NATIONAL TECHNICAL UNIVERSITY OF UKRAINE
" IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE"
INSTITUTE OF ENERGY SAVING AND ENERGY MANAGEMENT
DEPARTMENT OF AUTOMATION OF ELECTRICAL AND MECHATRONICAL COMPLEXES

«On the rights of the manuscript»
UDC 62-505

Admitted to the defense
Head of the department
_______ Serhii BOICHENKO
«___»____________20__.

MASTER THESIS
for a master's degree
by specialty141 "Electric power engineering, electrical engineering and electromechanics"
educational program (specialization) "Engineering of intellectual electrical engineering and mechatronic complexes"

by the topic: «Robust control of elevator drive taking into account backlash of gearbox»

Performed by:
student of the 2nd year study, group OA-22mp:
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Scientific supervisor:
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I certify that in this master's thesis there are no borrowings from the works of other authors without appropriate references.
Student ____________

Kyiv – 2023

National technical university of Ukraine

"’Igor Sikorsky Kyiv polytechnic institute"

Institute of energy saving and energy management

Department of automation of electrical and mechatronic complexes

The level of higher education is the second (master's) according to the educational and professional program

by specialty141 "Electric power engineering, electrical engineering and electromechanics"

educational program (specialization) "Engineering of intellectual electrical engineering and mechatronic complexes"

APPROVED BY:

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«___»_____________20__.

TASK

for a student's master's thesis

to Qiuyang Ding

1. Dissertation topic "Robust control of elevator drive taking into account backlash of gearbox", scientific supervisor of the dissertation Toropov Anton Valeriyovych, Associate Professor, Ph.D. approved by order of the university dated "___"_________20__ year No._____
2. The deadline for the student to submit a dissertation
3. Investigation object: The electric drive of the elevator installation is based on an asynchronous motor and a worm gear with an installed external position feedback sensor.
4. Input data: position electric drive control system with significant influence of backlash
5. The list of tasks to be developed: to carry out investigation of position drives; to develop robust regulator, which could be easy realized using PLC or other microprocessor systems; to carry out investigation of dynamics of system using mathematic modeling.
6. Oriented list of graphic (illustrative) material _____________________
7. Oriented list of publications: work in conference according to specialty with publication of master thesis results.

8. Consultants of Master thesis chapters

Section	Name, Family Name and Position of Consultant	Signature	
		Task issued	Task accepted
Nataliia Shevchuk			

9. Date of issue the task____

Calendar plan

No.	The name of the execution stages master's thesis	The deadline for completing the stages of the master's thesis	Note
1	Selection and approval of the topic.		
2	Selection and familiarization with the literature.		
3	Drawing up a plan, developing an individual task and calendar plan.		
4	In-depth study of literary sources and writing of the theoretical part.		
5	Collection and analytical processing of materials on the research topic		
6	Writing a master's thesis and its design.		
7	The supervisor's feedback on the master's thesis		
8	External review of master's thesis		
9	Submission of a master's thesis to the SEC and its defense		

Student Qiuyang DING

Master thesis supervisor Anton TOROPOV

Анотація

В магістерській дисертаційній роботі розглядається питання побудови регуляторів для систем позиціонування. дисертаційної роботи і розглянуті питання використання різних регуляторів для систем точного позиціонування підйомних установок.

В першому розділі розглянуті різні типи електропривода змінного струму та способи керування ними. Визначено, що найбільш популярним в Україні є системи змінного струму на базі асинхронного двигуна із короткозамкненим ротором, що працює від перетворювача частоти. Для зниєження швидкості використовуються червячні редуктора. Таке рішення є відносно дешевим, хоча й не енергоефективним. Недоліком існуючих систем такого типу є вплив люфтів редуктора на перехідні процеси при позиціонуванні. Визначено, що в перехідних процесах у випадку великого люфта в системі можуть виникати коливальні процеси, що недопустимі для ліфтових установок. Тому розглянуті системи позиціонування із складнимим регуляторами.

В другому розділі здійнсено вибір елементів електропривода змінного струму і розраховані параметри математичяної моделі для дослідження. Запропонований до використання робастний регулятор із каналом підвищення коефіцієнту підсилення, що забезпечує нечутливість системи до зовнішніх та внутрішніх збурень.

В тертьому розділі синтезований регулятор перевірено на працездатність з використанням математичного моделювання МАТЛАБ. Також працездатныстъ реалізації регулятора перевірено за допомогою моделі в середовищі Кодесіс 2.3.

В розділі стартапу надано рекомендації по впровадженню системи керування.

Ключові слова:

робастний регулятор, позиціонування, перетворювач частоти, коефіцієнт підсилення, бажана передаточна функція

Abstract

The issue of building regulators for positioning systems is considered in the master's thesis. Dissertation work and discussed the use of various regulators for precise positioning systems of lifting installations.

In the first chapter, different types of AC electric drive and ways of controlling them are considered. It was determined that the most popular in Ukraine are alternating current systems based on an asynchronous motor with a short-circuited rotor operating from a frequency converter. Worm reducers are used to reduce the speed. Such a solution is relatively cheap, although not energy efficient. The disadvantage of existing systems of this type is the effect of gear backlashes on transient processes during positioning. It was determined that in transient processes, in case of a large backlash in the system, oscillating processes may occur, which are unacceptable for elevator installations. Therefore, positioning systems with complex regulators are considered.

In the second section, the elements of the alternating current electric drive are selected and the parameters of the mathematical model for research are calculated. A robust regulator with a channel for increasing the amplification factor is proposed for use, which ensures the insensitivity of the system to external and internal disturbances.

In the third section, the synthesized regulator is checked for performance using MATLAB mathematical modeling. The operability of the controller implementation was also checked using the model in the Codesys 2.3 software.

The startup section provides recommendations for implementing a control system.

Keywords:

robust controller, positioning, frequency converter, gain, desired transfer function

CONVENTIONAL ABBREVIATIONS

P - a proportional regulator

PI - proportional-integral controller

PID - proportional-integral-differential regulator

PC - personal computer

IM – induction motor

FI – frequency inverter

PLC is a programmable logic controller

CONTENT

INTRODUCTION

The highest accuracy of the positioning of the cabin is achieved with the use of sensors installed on the output shaft of the executive mechanism or linear movement. At the same time, the presence of backlash and elastic connections in the electromechanical system and the working body is taken into account. At the same time, the inclusion of backlash in the adjustment circuit can lead to the appearance of auto-oscillations of the output coordinate, especially when using classical linear regulators. This effect is manifested when trying to increase the speed of the drive by increasing the gain of the entire system. Also, it should be remembered that the self-oscillation mode reduces the accuracy of adjustment, and also has an extremely adverse effect on the operation of the mechanical part of the electric drive, causing premature wear of shafts, couplings, and reducers. Currently, the synthesis of correction devices, which is carried out on the class of linear control laws using the method of correction according to the desired transient process, has become widespread. At the same time, a corrective signal is formed, depending on the deviation from the desired ideal transition process.

Investigation actuality. Recently, the electric drives of elevator installations have been subject to increasingly high requirements for positioning accuracy. At the same time, costs for the modernization of the cabin lifting mechanism are reduced to a minimum, which makes it impossible to use gearless low-speed motors of the synchronous type with permanent magnets on the robot shaft. Since in Ukraine the most popular electromechanical system of the elevator remains the asynchronous motor with a worm gear, controlled from the frequency converter, increasing the accuracy of positioning in such conditions is achieved only by improving the control algorithms under the condition of installing inexpensive drive coordinate sensors.

The goal of the work. The purpose of this work is to develop a robust control algorithm that takes into account the presence of significant nonlinearities in the "backlash" circuit. To achieve this goal, a Proportional correction regulator is used for the deviation from the desired ideal initial process.

Object of investigation. The electric drive of the elevator installation is based on an induction motor and a worm gear with an installed external position feedback sensor.

Subject of investigation. A robust software control algorithm that takes into account the influence of the backlash transmission function.

The scientific novelty consists in the development of a robust control system with a significant increase in the ratio of the variable system with the possibility of implementation on programmable logic controllers.

Practical results. The proposed control algorithm, implemented in the programming language of programmable logic controllers ST, can be used to implement control systems for elevator installations with increased requirements for positioning accuracy.

Publications. 1) Toropov A.V. Robust control of position electric drives taking into account gearbox backlash / Toropov A., Toropova L., Ding Q.// Problems of modern power engineering and automation in the system nature management (theory, practice, history, education) Proceedings of the X International Scientific-Technical Conference Kyiv, 19 of October, 2023. pp. 52-53. 2) Toropov A., Bosak A., Toropova L. Kulakivsky L, Ding C. Systems, Decisions and control in Energy VI. Optimization of Double Inverter-Feed Drive Work According to Minimum of Dinamic Error Criteria, 2023 (accepted for publication).

Approbation of work. The results of the master's thesis were reported at the 10th International scientific-practical and educational-methodological conference "Energy management: state and prospects for development - PEMS'23", which took place at I. Sikorskyi KPI on November 22-24, 2023, and at the 10th International Scientific - technical online conference "Problems of modern energy and automation in the system of nature management" (theory, practice, history, education) on October 23, 2023

CHAPTER 1. ANALYSIS OF EXISTING SCHEMATIC SOLUTIONS FOR POSITIONING SYSTEMS OF ELEVATOR INSTALLATIONS

1.1 Research background and significance of the topic

Elevator is an indispensable vertical transportation tool in high-rise buildings in today's world, especially in modern society and economic and trade activities, elevator has become a symbol of urban material civilization. As a vertical transportation lifting equipment, elevator occupies a small area in high-rise buildings, and at the same time, passengers and goods can be sent to different floors safely, reasonably and efficiently through electrical or other means of control. Because of these advantages, in the rapid rise of ultra-high-rise buildings today, elevators and elevator technology have become an important part of people's work and life is closely related.

As a device that uses electricity, the energy consumption of elevators accounts for about 8% of the overall energy consumption of the building, of which the elevator traction machine and drive control system are the main objects that use electricity. The traction machine is the core component of the elevator, which usually consists of electric motor, brake, reducer and base, etc. Traditional traction machines are mostly three-phase asynchronous motors. The traditional traction machine is mostly a three-phase induction motor, which has a reduction gearbox, making the traction system complicated in structure, bulky in size, low in motor efficiency, and noisy and vibrating in operation, and difficult in installation and maintenance. At present, the permanent magnet synchronous traction machine is generally used in 1.5 ~ 2.0m / s of medium and high speed elevator, due to the use of permanent magnet materials to provide excitation, reducing the rotor loss, so that the main structure of the motor is more compact, the volume is reduced, can be realized in a small machine room or no machine room layout, saving a certain amount of building space, increase the available area of the building. Therefore, domestic and foreign companies are actively researching and developing induction synchronous traction machines and launching them on the market. In response to this development trend, this article takes radial magnetic field induction synchronous traction machines as the research object, and conducts more in-depth research on their basic structure, theory, operational performance, and electromagnetic design.

Ding Kang and Wang Yanchun discuss the effect of excitation energy on the vibration modulation phenomenon generated by gear tooth failure and shaft bending, point out that three different modulation phenomena in gearboxes: gear mesh frequency modulation, gear intrinsic frequency modulation and transmission box intrinsic frequency modulation is the fundamental reason for the different excitation quantities, and at the same time, put forward corresponding vibration troubleshooting methods of gearboxes and successfully apply them to the gear tooth failure and shaft bending. engineering examples. Chen Zhong and Zheng Shixiong [6] briefly describe the similarities and differences between the traditional signal analysis techniques and the empirical mode decomposition (EMD) techniques for gearboxes, and discuss in detail the relationship between the decomposition principle of EMD and the Fourier transform. By applying the EMD decomposition technique, the gearbox vibration acceleration data are decomposed to obtain the IMF (Intrinsic Mode Function) mode component, and then two corresponding failure reference indicators are proposed, and their validity and operability are verified under specific conditions to provide a reference method for the fault diagnosis of gearbox vibration.

The failure and fault diagnosis of gears and gearboxes in industrial production have attracted the attention of scholars from various parties. Elevator belongs to special equipment, which is closely related to the daily life of the people, especially the abnormal vibration of the drive mainframe has a significant impact on the safety of the elevator [7], so the failure analysis of the worm gear of the elevator traction machine reduction gearbox is imminent.

1.1.1 Common Traction Machine Gearbox Worm Gear Failure Form

Among the gearboxes for geared traction machines, worm gearboxes are the most commonly used. Worm usually choose 45 steel or 40Cr material, generally Archimedes spiral worm. Worm gear should usually be selected from tin bronze or aluminum bronze casting materials, but now due to vicious competition in the industry leading to a substantial reduction in production costs, so the current are a large number of high-aluminium zinc-based alloy materials to replace. This alternative material is cheap, light weight, good mechanical properties, but the disadvantage is the high thermal sensitivity, high requirements for casting, prone to porosity, porosity and slag and other defects. Due to material and structural factors, the strength of the worm gear is generally higher than that of the worm wheel, so it is usually the gear teeth of the worm wheel that fail.

The gearbox of elevator traction machine is usually a closed environment, due to poor heat dissipation conditions, and continuous long time heavy load operation, so the worm gear worm gear is very easy to fail. The more common forms of worm gear tooth failure in engineering applications are: tooth surface gluing, tooth surface wear, tooth surface pitting, tooth fracture and tooth surface plastic deformation. In the gearbox of elevator traction machine, tooth wear and tooth fracture are the most common.

1.2 Overview of the development of robust control theory

Traditional control theories and methods, such as classical control theory, modern control theory and adaptive control theory, require an accurate model of the control object or require the uncertainty of the object model and external disturbances to satisfy special assumptions, however, in the actual control system, it is difficult or even impossible to obtain an accurate model of the control object, and the uncertainty of the object and external disturbances often do not satisfy the specificity of the assumptions. Therefore, the design of a control system must consider whether the controller can still stabilize the control system and meet the desired requirements in the presence of uncertainty.

In the 1980s, it was increasingly recognized, both practically and theoretically, that when designing a control system, it is unrealistic to base it on an exact model of the system, and that its uncertainty must be analyzed, which led to the emergence of robust control theory, a control theory that specializes in analyzing and dealing with systems with uncertainty [15].

Notable robust control theories include H∞ control theory, structural singular value theory and Kharitonov interval theory. Among them, H∞ control theory is a more successful and complete theoretical system to solve the robust control problem, which has become one of the popular topics in automatic control theory and engineering application research in the past 20 years [49]. The robustness of a control system generally refers to the ability of the system to maintain a certain original quality when its parameters or structures are regulated. Robustness includes robust stability and robust performance. Robust stability is the ability of a system to remain stable when its parameters or structure are subjected to an uptake, and robust performance is the ability of a system to maintain a particular performance when its parameters or structure are subjected to an uptake [12].

H∞ control was first developed from the frequency domain. It was found that many problems in the design of control systems could be reduced to minimizing the H∞ paradigm of a certain closed-loop transfer function, or less than some specified positive number.H∞ control has gained impressive development through the efforts of many researchers over the years, and gradually formed a complete set of theoretical systems, which has become a powerful tool for analyzing and designing uncertain systems [15].

In the 1960s, the state-space method known as modern control theory was greatly developed, and the LQG feedback design (H2 control) method based on Kalman oscilloscope and optimal quadratic regulation theory appeared. However, the LQG design method requires that an accurate model of the object be obtained, and it is assumed that the statistical characteristics of the external disturbance signal are known. The above conditions are often difficult to achieve in practical applications, so the LQG design method is not successful in practical applications although it has better results in theory. For the LQG design of the required limitations of the interference signal irrationality, the Canadian scholar Zames in 1981 put forward the famous H ∞ control idea. Zames consider the following a single-input single-output system design problem: for belonging to a finite energy set of interference signals, the design of a controller to make the closed-loop system is stable and the interference of the system to minimize the impact of the desired output. Since the H∞-parameter of the transfer function describes the maximum gain of a finite input energy, the H∞-parameter of the transfer function, which represents the effect described above, is used as the objective function to optimize the design of the system, so that the interference, which has a finite power spectrum, will have a minimum effect on the desired output of the system. It can be seen that using the H∞ paradigm as a performance metric also has the following advantages:

(1) It can deal with the control of the system under bounded disturbances.

(2) The H∞ paradigm has the multiplicative property that $PQ\infty \leq P\infty Q\infty$, a property that makes it convenient to study robust stability problems when the object has uncertainty.

The development of H∞ control can be roughly divided into three periods from 1981 when Zames proposed the idea of H∞ control to the present [14][49]:

(1) The first period was from 1981 to 1984, of which the representative work was the so-called "1984 method" proposed by Doyle et al. in 1984.

(2) The second period is from 1985 to 1988, during which H∞ control made a breakthrough, and in 1988, Glover

and Doyle gave the solution of the famous "2-Riccati equation".

(3) The third period is from 1989 to the present, which is the period of refinement and popularization of H∞ control theory.

Since Zames's H∞ control idea is a frequency domain design technique, the initial research methods for H∞ control were frequency domain or frequency domain plus time domain methods. In this period, H∞ control theory mainly used approximation methods and interpolation methods. The interpolation method uses Nevanlinna-Pick interpolation theory and Sarason theory in matrix form, which has the advantages of conceptual intuition and clarity, but does not give good algorithms;

while the approximation method has made some progress in computation with the help of AKK theory, and its shortcoming lies in the fact that the theory used is relatively esoteric and difficult to understand. In the 1984 year, Doyle and Glover et al. conducted a study of the H∞ control theory. In 1984, Doyle and Glover summarized the H∞ control at that time and formed the "1984 method".

Due to the effects of both model uncertainty and disturbances in real systems, H∞ control, an optimization design approach

The method has evolved from a sensitivity minimization problem to a hybrid sensitivity optimization problem where the system is designed to ensure robust stability and good performance [27]. To deal with this problem, initially, Kwakernaak's polynomial method was used, i.e., the problem was transformed into polynomial and matrix equations to be solved.

The study of robust stabilization for systems with model uncertainty is an important aspect of H∞ control, which

There is a parallel with the sensitivity minimization and hybrid sensitivity problems. Briefly, there is the following relationship: additive and multiplicative regressions correspond to sensitivity minimization, while numerator and denominator regressions correspond to hybrid sensitivity optimization.

In the process of studying various H∞ optimization problems, it has been found that the sensitivity minimization problem, robust calibration problem, mixed sensitivity optimization problem, tracking problem, two-degree-of-freedom problem, filtering problem, model matching problem, and many other control problems can be unified in the standard H∞ control problem (Francis, 1987), which has made the study of H∞ control theory more organized and has had a significant impact on the H ∞ control theory system has had an important impact on the formation of the system.

The year 1987 can be regarded as the year when H∞ control breeds a breakthrough.Ball and Cohen simplified Ball and Helton's geometric theory and reduced the problem of solving H∞ control to the decomposition of spectra and J-spectra, thus obtaining the 3 Riccati equations. This method has had a significant impact on the formation and refinement of the later J-spectral decomposition method, (J,J′)-nondestructive decomposition methods, and its communication with interpolation methods and polynomial methods, as well as the formation and refinement of (J,J′)-nondestructive decomposition methods, and its communication with interpolation methods. as well as its communication with interpolation methods and polynomial methods had an important influence.

Kimura used directional interpolation to solve the 2-block problem. In order to overcome the drawbacks of the interpolation method, which does not have an efficient algorithm, Kimura introduced the concept of "co-choking", which is inspired by the classical electrical network design method. "Co-choking" is a state-space description of the classical interpolation theory, which is a powerful tool for computing the (J,J′)-lossless decomposition and heralds the emergence of effective state-space algorithms with the advantages of the original interpolation method.

Limebeer et al. investigated upper bounds on the order of controllers for 2-block problems and suggested that controllers can be obtained whose number of states does not exceed the order of the generalized object, leading to optimistic conjectures that similar conclusions should be drawn for general 4-block problems.

The H∞ state feedback control problem was studied by Khargonekar et al. who created an algebraic Riccati equation solution method for H∞ control. This mainly stems from a robust stability problem for a system containing uncertainty, i.e., finding a controller that maximizes the complex stability radius of a system with structured uncertainty. They transformed this problem into an H∞ paradigm optimization problem for a certain system, and obtained that a sufficient condition for the H∞ state feedback control problem to have a solution is that an algebraic Riccati equation (parameterized ARE) with positive parameters has a positive definite solution. This result has important implications for the development of state-space solutions for H∞ control. In addition, this method establishes a connection between H∞ control and quadratic calibration and linear-quadratic differential countermeasures, which contributes to the emergence and development of later differential countermeasure methods. Its shortcoming is that the parameterized ARE is not easy to test. Unfortunately, this research direction was not further pursued at that time. Later, it was found that the nonparametric ARE could be obtained by introducing some restrictions on the generalized objects, which was one of the breakthrough results in 1988.

With the above accumulation, by the summer of 1988, a breakthrough was made in the study of H∞ control problems, and the solution of the standard H∞ control problem with the well-known "2-Riccati equation" appeared. Specifically, only two uncoupled algebraic Riccati equations need to be solved to obtain an H∞ controller whose order does not exceed the McMillan order of the generalized object. 1989, Doyle et al. summarized the state-space analysis of the H∞ control problem and emphasized the connection between the H∞ control problem and the LQG control problem so that the H∞ control problem has been greatly simplified in both conceptual and algorithmic aspects. algorithmic aspects are greatly simplified. Together with the appearance of program packages containing the above solutions, such as Robust-ControlBox, Matrixx, and Xmath, the H∞ control theory started to become an effective tool for the design of some practical systems. At that time, the paper of Glover and Doyle only gave the solution of the "2-Riccati equation" for H∞ control, but did not give the specific derivation procedure, and the systematic derivation method appeared in the following years after 1988, and Green et al. developed the work of Ball and Cohen, and transformed the H∞ control problem into two J-spectrum problems. Green et al. developed the work of Ball and Cohen by transforming the H∞ control problem into a 2 J-spectral decomposition problem and gave a more unified and systematic solution.Glover et al. discussed the generalized distance problem by using the extended and all-pass embedding methods, which had a complicated derivation. Kwakennaak's polynomial method was also developed, which can transform the H∞ control into a 2 J-spectral decomposition of the numerator and the denominator of a rational polynomial function, a result similar to the one of Green et al. based on the J-spectral decomposition of the numerator and the denominator. Green et al.'s solution based on the theory of J-spectral decompositions is quite strongly related.

After 1988, pure time-domain solutions for H∞ control appeared. Among them are the differential countermeasure method and the great value principle method. The application of differential countermeasure methods is very natural from the point of view of H∞ control ideas. These two methods can be used to solve H∞ control problems not only for linear time-invariant systems, but also for time-varying systems, distributed-parameter systems, nonlinear systems, singular regimes, etc [30].

Kimura proposed a solution to the H∞ control problem based on the (J,J′)-nondestructive decomposition theory by using the concept of "cochaining" and the scattering model of a generalized object that better reveals the series structure of the H∞ control system [29]. The (J,J′)-nondestructive decomposition is a decomposition method with some generality, such as inner and outer decomposition, spectral decomposition, etc. are its special cases. This solution method further reveals the structure of the H∞ control system, such as the energy relationship between the input and output signals, the structural decomposition of the generalized objects and the relationship between the controllers, etc. It also has the advantages of a simple derivation process and clear physical significance compared to other algorithms.

1.3 Elevator Systems

1.3.1 Classification of elevators

There are many ways to classify the elevator, the common ones are classified according to the use of elevator, classified according to the dragging method, classified according to the driving system, classified according to the type of traction machine, classified according to the rated speed of the elevator and so on.

According to the use of classification elevator can be divided into passenger elevator, freight elevator, sightseeing elevator, escalator, hydraulic elevator, machine room-less elevator, moving walkway, medical elevator, car elevator, miscellaneous ladder and so on.

There are DC elevators, AC elevators, hydraulic elevators and linear motor-driven elevators according to the dragging method.

According to the driving method elevator can be divided into traction drive, forced drive, hydraulic drive, etc., of which, because the traction drive elevator running stroke is higher, so in the high-rise building in the high-speed elevator often use traction drive.

The classification by tractor type, rated speed and drive method is explained.

(1) Classification by rated speed

According to the different rated speeds of elevators, elevators can be divided into low-speed elevators, fast elevators, medium and high speed elevators and super-speed elevators.

High-speed elevator, its classification of elevator speed is shown in Table 1.1

Table 1.1. Classification of elevator speed

	Low-speed elevator	Express Elevator	Medium and high speed elevator	Ultra High Speed Elevator
Tempo	v≤1m/s	1m/s<v≤2m/s	2m/s<v≤6m/s	v>6m/s

Low-speed elevator: the running speed of the elevator is v≤1m/s, which is generally used for freight elevators with large loads.

Fast elevator: the running speed of the elevator is 1m/s<V≤2m/s, mostly used in small high-rise (within 15 floors).

High-speed elevator: elevator operating speed 2m/s <V≤6m/s, generally in high-rise office buildings, and single, double or high, low area of the elevator operating speed is mostly in the range of values, and for the rated speed of this paper for the 4m/s traction elevator collectively referred to as the high-speed elevator.

Ultra-high-speed elevator: elevator running speed V>6m/s, for ultra-high-rise buildings, in which the elevator and the zoning control, such as from the first 20 floors above, and only in this way, can give full play to the role of ultra-high-speed elevator.

(2) Classification by tractor type

Elevators can be divided into two categories: geared elevators and gearless elevators. Gear elevator traction wheel speed and motor speed is not equal to the motor speed motor speed is greater than the traction wheel speed in the middle of the worm gear or gear planetary gear, helical gear reducer. Generally used in the elevator rated speed is not greater than 2.5m / s occasions. Gearless elevator has the traction sheave speed equal to the motor speed, and there is no worm gear or gear reducer in the middle. For this kind of elevator, the motor is required to have the characteristics of low rotational speed and large torque, which is generally used in the elevator with the rated speed greater than gripper. In recent years, with the progress of permanent magnet material and permanent magnet motor technology, as well as the development of electronic technology and control technology, the development and production of permanent magnet synchronous gearless traction elevator has been paid more and more attention by domestic and foreign elevator industry, and it is also commonly used in low-speed occasions.

(3) Classification by driving method

Elevators can be classified into traction elevators, hydraulic elevators, forced-drive elevators, etc. according to the driving method.

Hydraulic elevator is the emergence of an earlier elevator, the beginning of the use of water as a medium, by pressurizing the water, the use of water incompressibility to promote the outward movement of the plunger, and then realize the elevator car upward; when the elevator needs to go down, the use of the relief valve will be discharged out of the water, which is the elevator car in the role of its own gravity downward, but because of the transmission medium is the water will lead to the cylinder rust, and then gradually replaced by oil. After that, it is gradually replaced by oil. Hydraulic elevator has a large load, easy to install and other advantages, but the disadvantages are also very obvious lifting height is small, high power input. Now the height of the building is constantly high, resulting in the mainstream elevator on the market now most of the use of steel wire rope, the main principle of motion of this elevator is the use of steel wire rope and friction between the traction sheave, as well as the use of hanging weights to achieve the upward and downward movement of the car, the use of brakes to achieve the elevator brake.

The traction elevator adopts the traction sheave as the driving part, the traction wire rope is suspended on the traction sheave, and the two ends are connected to the car and the counterweight respectively, relying on the friction between the traction wire rope and the groove of the traction sheave to generate traction force to drive the car to do up and down operation. Hydraulic elevator is the use of electric pumps to drive the liquid flow by the plunger to make the car lift elevator. Forced-drive elevator is a non-friction driven elevator suspended by chain or wire rope. Because the elevator with traction drive has good controllability and safety, strong adaptability to the building, and relatively simple manufacturing and installation, so most of the elevators in use and sales are these elevators, especially in the field of medium and high speed. The traction elevator is the most important type of elevator, and the research of this thesis is also based on the traction elevator.

1.3.2 Composition of traction elevator

As a complex electromechanical system, the elevator system is divided into 8 systems, including traction system, car system, guiding system, weight balancing system, safety protection system, electric traction system, electric control system and door system, according to the functions and roles assumed by each mechanical component or electric element, as shown in Figure 1.

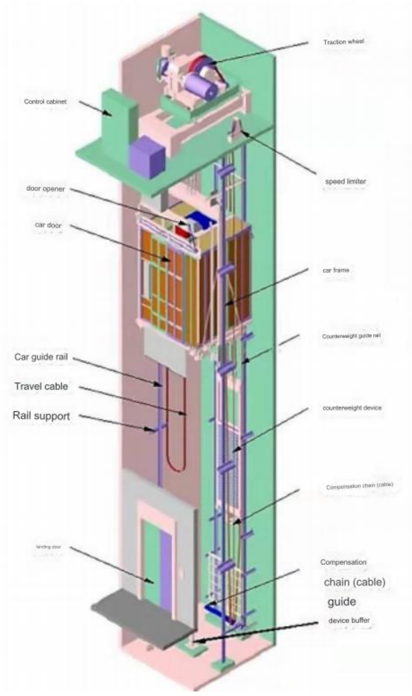

Figure 1.1 Elevator system structure

The specific composition and function of its systems are shown in Table 1.2

Table 1.2 The specific composition and function of its systems

System name	Ingredient	Functionality
Traction system	Traction machine, wire rope, guide, sheaves, counter sheaves, etc.	Used to output power so that the elevator has sufficient traction force
Car systems	Car body and frame	The function is to carry and protect passengers or cargo
Guidance system	Guideway, Guideway Attachment Plate, Guideway Holder and Guide Shoe	Make the car frame and counterweight have the freedom of vertical direction degree of freedom in the vertical direction, under the guidance of the guide rail to do lifting and lowering motion
Weight balancing	Counterweight and weight compensation devices	Balancing the car system, the weight of the load and the upper floors

system	(Compensation chain)	Compensating for the effect of the length of the traction rope in an elevator
Security Protection System	Speed Limiters, Safety Clamps, Buffers Speed Limiters, Safety Clamps, Buffers, Limit Protection Devices	Protect the safety of passengers and elevators and prevent all accidents that jeopardize personal safety
Power drag system	Traction motor, motor speed control unit, speed feedback unit and power supply system	Provides speed control for elevators
Electrical control systems	Maneuvers,leveling, control device, maneuvering device, leveling device, position display device, etc.	Manipulate and control elevators
Door system	Floor doors, car doors, door systems, door locks and linkage mechanism, etc.	ingress and egress of passengers or transported goods, running (It is also the first line of defense to protect the safety of passengers on the elevator)

The traction system mainly consists of traction machine, traction rope, guide sheave and counter sheave. The traction machine consists of an electric motor, coupling, brake, reduction gearbox, seat, traction sheave, etc. The structure varies depending on the type of traction machine (geared, gearless). Depending on the type of traction machine (gear, gearless) different structures are different. It is the power source of the elevator. The two ends of the traction wire rope are connected to the car and the counterweight (or both ends are fixed in the machine room, relying on the friction between the wire rope and the rope groove of the traction sheave to drive the car up and down. The role of the guide pulley is to separate the distance between the car and the counterweight, the use of rewinding can increase the traction capacity. The guide pulley is mounted on the traction machine base or load bearing beam. When the rope winding ratio of the traction rope is more than 1, additional counter rope sheaves are installed on the car roof and counterweight frame. The number of counter sheaves can be 1, 2 or even 3, depending on the winding ratio.

The traction system of the elevator is the main power source of the elevator operation, and the traction machine is just like our human heart for the elevator, so its performance directly affects the speed, acceleration and reliability of the elevator during normal operation [20-22]. Elevator braking test mainly examines the braking performance and traction performance of the elevator, and in the elevator structure, these two properties are mainly dependent on the traction sheave and brake to achieve the material and structural properties of the traction sheave mainly affects the magnitude of the elevator's traction capacity, and the performance of the brake determines the strength of the elevator's braking capacity.

In reality, rope grooves are machined into different shapes in order to increase the friction of the rope in them. At present, there are several shapes of the groove of the traction sheave, but the most widely used is the semicircular groove with a notch, also known as a concave groove, this groove is formed on the basis of semicircular groove machining, in the bottom of the semicircular groove in the machining of a wedge-shaped groove, the advantage of this design is that with the wear and tear of the center of the groove appears to be downward, but the size of the central angle does not change. This advantage also makes this kind of slot in the elevator has been widely used, the brake mainly relies on the electromagnetic force and spring elasticity, when the elevator is in normal operation, the electromagnetic force in the brake is greater than the elasticity of the braking spring, the brake is in the state of release. When the elevator needs to brake, the braking force of the brake disappears, and the brake is in the holding state.

The traction machine, also known as the elevator, drive main engine, is the power source of the elevator. Conveying and transferring power to make the elevator run normally is the main function of elevator traction machine. In the rapid development of elevator technology today, traction machine is generally divided into geared traction machine and gearless traction machine, the more common is geared traction machine. A geared elevator traction machine usually consists of an electric motor, coupling, brake, reduction gearbox, traction sheave, frame and guide sheave, as well as an accessory emergency coiling device and other components. A geared elevator traction machine usually utilizes a reduction gearbox to transmit motor power to the traction sheave to achieve the power transmission and reduction ratio requirements. In order to improve the smoothness of the elevator operation, reduce the operation noise and the size of the reduction gearbox, a worm gearbox is generally used. According to the arrangement of worm gear, it is usually divided into upper and lower type.

1.4 Analysis of Induction Motors

1.4.1 Introduction to motor traction machine

The traction machine is the equipment that provides elevator power. It can also be called the elevator host. Its main function is to transport and transmit power. The force makes the elevator move up and down. The traction machine consists of motor, brake, traction wheel, reduction box, coupling, frame and guide. It consists of a directional wheel and an accessory turning hand wheel. The guide wheels are generally installed on the frame or the load-bearing beam under the frame. The turning wheel has some are fixed on the motor shaft, and some are usually hung on a nearby wall, and then put on the motor shaft when in use. Traction machines are classified according to whether they have reducers or not: geared traction machines (as shown in the figures 1-3 shown) and gearless traction machines.

Figure 1.2 Geared traction motor

Geared traction machine: If the motor power of the traction machine is transmitted to the traction sheave through the reduction gearbox, It is called a geared traction machine and is generally used for medium and low speed elevators below 2.5m/s . The power of the dragging device is transmitted to the traction machine on the traction wheel through the intermediate reducer. In order to increase the stability of the traction machine during operation, The reduction box usually uses a worm gear transmission device. This transmission method has the advantages of smooth transmission, large transmission ratio, and compact structure. Gearless traction machine: If the power of the motor is directly transmitted to the traction wheel without passing through the reduction gearbox, it is called a gearless traction machine. It is generally used for 2.5m/s In the above high-speed elevators and ultra-high-speed elevators, the power of the driving device does not need to go through the reducer but is directly transmitted to the traction machine on the traction sheave . In the past, most of these traction machines were powered by DC motors. At present, AC permanent magnet synchronous gearless traction machines with independent intellectual property rights have been developed in China, such as Xuchang Boma traction machine.

Although the use of permanent magnet synchronous traction motors in elevators can achieve better overall performance, the main features are: low wear, Energy saving, easy installation, smooth operation, fuel saving, easy to use, etc., but the price is much higher than that of asynchronous motors. Moreover, many old-fashioned elevator systems still use asynchronous motor plus transmission structure . Large and difficult to move out of the building things, In order to improve the performance of the elevator system, only the control system part is replaced. All integrated controller products currently on the market have the capabilities of both three-phase asynchronous motor vector control and permanent magnet synchronous motor vector control. Therefore, the ability to control the three-phase asynchronous motor is also measured. The key points of the performance of the elevator integrated controller, this article focuses on the vector control of the three-phase asynchronous motor.

The motor used in this article is a three-phase asynchronous motor produced by Nanjing Kunpeng Motor Manufacturing Co., Ltd. As shown in the Figure 1.3

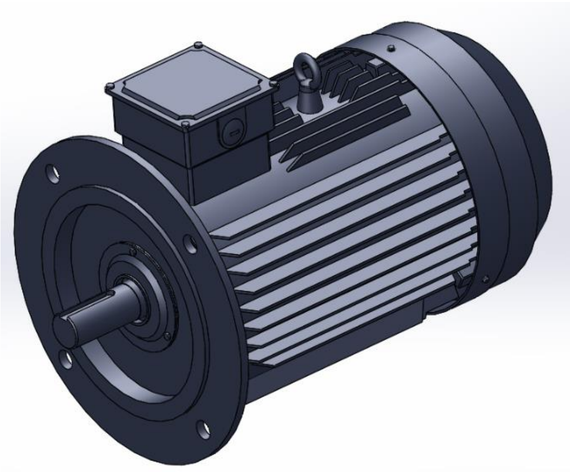

Figure 1.3 Three-phase asynchronous motor

The specific parameters of the motor are as follows:

Rated voltage	380V (three-phase)
Rated current	17A
Power	7.5kw
Rated operating frequency	50Hz
Number of poles	6
Rated speed	970r/min

Table 1.3 Parameters of the motor

A three-phase asynchronous motor (also known as a three-phase induction motor) is a type of electric motor widely used in industrial and commercial applications. Its main features are simplicity, reliability and efficiency. The following are the basic principles and characteristics of three-phase asynchronous motors:

Fundamental

1. Structure:

A three-phase asynchronous motor is mainly composed of two parts: the stationary part is called the stator, and the rotating part is called the rotor.

There are three sets of coils on the stator, distributed at an angle of 120 degrees, connected to a three-phase AC power supply.

2. Generate a rotating magnetic field:

When three-phase current flows through the stator coil, a rotating magnetic field is generated within the stator.

The speed of this magnetic field is called synchronous speed and is related to the frequency of the power supply and the number of poles of the motor.

3. Induction and rotor rotation:

A rotating magnetic field passes through the rotor and due to electromagnetic induction, an induced current is generated in the rotor.

The induced current is acted upon by the magnetic field, pushing the rotor to rotate.

The rotational speed of the rotor is lower than the synchronous speed of the magnetic field. This speed difference is called slip.

Features and Applications

1. Efficiency and reliability:

Three-phase asynchronous motors have high efficiency, strong reliability and low maintenance costs.

No brushes and commutation components, so less wear and smooth operation.

2. Self-starting capability:

Ability to start directly from rest, no additional starting mechanism required.

3. Speed control:

Although speed control is not as flexible as synchronous motors, better speed regulation can be achieved through frequency converters.

4. Wide application:

Widely used in pumps, fans, compressors, conveyor belts, elevators, machine tools and other occasions.

5. Frequency conversion speed regulation:

Combined with variable frequency technology, three-phase induction motors can operate efficiently in a wider speed range to meet the needs of specific applications. Due to their durability high efficiency and wide applicability, three-phase asynchronous motors play a vital role in modern industry.

1.4.2 Mathematical model and slip frequency control of three-phase asynchronous motor in MT axis coordinate system.

For asynchronous motors, if the comprehensive flux vector along the rotor is specified ψ_r The direction is M axis, take relative M axis Ahead of time 90 The direction of degrees is T axis direction, thus forming a rotation axis rotating at synchronous speed ω_s MT coordinate system, then the voltage equation of the three-phase induction motor is formula(1.1) .

$$\begin{bmatrix} U_M \\ U_T \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + pls & -\omega_s L_s & pL_m & -\omega_s L_m \\ \omega_s L_s & R_s + pL_s & \omega_s L_m & pL_m \\ pL_m & 0 & Rr + pL_r & 0 \\ (\omega_s - \omega_{re})L_m & 0 & (\omega_s - \omega_{re})L_r & R_r + pL_r \end{bmatrix} \begin{bmatrix} i_M \\ i_T \\ i_m \\ i_t \end{bmatrix} \tag{1.1}$$

In the formula U_M , U_T - stator voltage under T axis; i_M, i_T - stator current under T axis; i_m, i_t - Rotor current under T axis; ω_s, ω_{re} - the synchronous speed of the motor and the electrical angular speed of the rotor rotation; R_s, R_r - the resistance of the stator and rotor windings; L_s , L_r - self-inductance of stator and rotor winding; L_m - mutual inductance between stator and rotor windings.

$$\begin{bmatrix} \psi_M \\ \psi_T \\ \psi_m \\ \psi_t \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_M \\ i_T \\ i_m \\ i_t \end{bmatrix} \tag{1.2}$$

In the formula ψ_M ,ψ_T - the stator flux linkage under the M and T axes available

$$\begin{cases} 0 = L_m i_r + L_r i_t \\ \psi_m = L_{miM} + L_{ri} \end{cases} \tag{1.3}$$

The stator voltage equation of the three-phase induction motor in the MT axis coordinate system remains unchanged, and the rotor voltage equation becomes:

$$\begin{cases} 0 = R_r i_m + P\psi_m \\ 0 = R_r i_t + \omega_{se}\psi_m \end{cases} \tag{1.4}$$

where ω_{se} is the slip electrical angular velocity of the rotor, $\omega_{se} = \omega_s - \omega_{re}$

From formula (1.4), we can get the formula:

$$i_T = -\frac{L_r}{L_m} i_t \tag{1.5}$$

This equation reflects the balance relationship between the torque component of the stator magnetomotive force and the rotor magnetomotive force. It actually represents the balance relationship of the magnetomotive force after the magnetic field is oriented. From formula (1.5) we can get:

$$i_m = -\frac{P\psi_M}{R_r} - \frac{P\psi_r}{R_r} \tag{1.6}$$

Since $\psi_t = 0$,the M- axis and T -axis windings of the motor are decoupled, that is, the T -axis winding has no influence on the M -axis winding, so only when the flux linkage ψ_m interlinked with the M- axis winding changes, the There is im. If the flux linkage ψ_{m} remains constant, it should be zero. At this time, $i_m \psi_m$ is only generated by the stator current, that is we have

$$\psi_m = \psi_r = L_m i_M \tag{1.7}$$

or

$$\psi_m = \psi_r = L_m i_M \tag{1.8}$$

It should be noted that the equations (1.7) and (1.8) can only be established under the condition that the rotor flux linkage ψ_{r} remains unchanged. In dynamic situations, the situation is different. Because

$$\psi_{\mathrm{r}} = L_m i_M + L_{\mathrm{r}} i_m = L_{\mathrm{m}} \left(i_M + \frac{L_r}{L_m} i_m \right) \tag{1.9}$$

So there is

$$i_{Mm} = \frac{\psi_r}{L_m} = i_m + \frac{L_r}{L_m} i_m \tag{1.10}$$

In the formula, i_{Mm} is the equivalent excitation current that generates the rotor flux linkage ψ_r .This shows that under dynamic conditions, ψ_r is jointly produced by i_{M} and i_{m} ,reflecting the result of this joint action. In steady state, $i_{Mm} = i_M$ .Substituting equation (1.7) into equation (1.9) we can get:

$$\psi_r = \psi_m = L_m \frac{i_M}{1 + T_r p} \tag{1.11}$$

In the formula, T r is the rotor constant, which defined by $T_r = L_r / R_r$.

From formulas (1.1) , (1.4) , (1.5), (1.7) , (1.11) , we can get the slip frequency vector control equation (P_n motor pole) according to the rotor flux orientation algorithm):

$$\begin{cases} i_M = \dfrac{1+T_r p}{L_m}\psi_r \\ i_r = \dfrac{T_r}{L_m}\psi_r \omega_{se} \\ T_e = \dfrac{3}{2}P_n L_m (i_T i_m - i_M i_t) = \dfrac{3}{2}P_n \dfrac{L_m}{L_r}\psi_r i_r \\ \omega_{se} = \omega_s - \omega_{re} = \dfrac{L_m R_r}{L_r}\dfrac{i_T}{\psi_r} = \dfrac{L_m}{T_r}\dfrac{i_T}{\psi_r} \end{cases} \tag{1.12}$$

So, we can define the importance and complexity of elevator position drive control, conduct extensive discussions on elevator traction systems and related induction motors, and provide the following key information:

Firstly, the introduction of elevator systems highlights the crucial role of elevators in modern architecture. This article provides an overview of the components of an elevator system and identifies the necessity of elevators in daily life. In addition, in-depth research on traction elevator components, including traction machines, ropes, motors, and control systems, helps to better understand the complexity of elevator systems and emphasizes the importance of precise position drive control. Secondly, the robust control theory was introduced and applied to solve the uncertainty and interference problems in elevator position drive control. This article emphasizes the importance of robust control, especially when dealing with complex control problems in elevator systems. Subsequently, the structure and working principle of the induction motor were discussed in detail. The key role of induction motors in elevator applications was emphasized, and the mathematical modeling method of induction motors was elaborated, laying a theoretical foundation for the design of subsequent control systems.

This article also emphasizes the complexity and importance of elevator position drive control. Elevators are an important component of modern life, requiring high precision to ensure safety and performance. The purpose of this chapter is to emphasize the meaning and challenges of elevator position drive control, and to provide clear focus for investigation.

CHAPTER 2. CONTROL SYSTEM DESCRIPTION FOR POSITIONAL ELECTRIC DRIVE WITH AN INDUCTION MOTOR AND BACKLASH

2.1 Detailed selection of components

The core power source of the elevator system is a three-phase induction motor, which not only converts electrical energy into mechanical energy to drive the elevator, but also directly affects the energy efficiency and operating costs of the entire system. The stability and reliability of this kind of motor are key factors to ensure the smooth operation of the elevator and the safety of passengers. Working closely with the motor is the worm gearbox, whose main responsibility is to reduce the high-speed rotation of the motor and at the same time increase the torque to adapt to the speed and force requirements of the elevator. The design of the gearbox, especially its backlash size, directly affects the positioning accuracy and response speed of the elevator, so it is crucial to ensure that the elevator stops accurately. In addition, gearbox durability and efficiency are key factors in determining system maintenance requirements and lifespan.

The optimal control of elevator operation relies on a high-efficiency frequency converter, which controls the speed of the motor by accurately adjusting the frequency and amplitude of the motor's power supply. This fine speed control not only improves overall energy efficiency and reduces energy consumption, but also significantly improves ride comfort. High-precision speed adjustment also improves the elevator's response speed and positioning accuracy, which is crucial to ensuring the efficient and safe operation of the elevator. Another key component in the elevator system is the position sensor, usually a high-precision encoder, which is responsible for providing real-time position information of the elevator to ensure that the elevator can accurately stop at the designated floor. The accuracy of the encoder is directly related to the safety of passengers and the operating accuracy of the elevator. In addition, the encoder data also contributes to system fault detection and diagnosis, which is a key link in maintaining stable operation of the elevator.

The brains controlling this complex system is the programmable logic controller (PLC), which handles input and output control instructions for all sensors. The reliability and programming flexibility of PLC are the keys to ensuring the safe operation of elevators. It is also responsible for communicating and integrating with other components of the system to ensure efficient operation and safe monitoring of the entire elevator system. Through high-level programming languages such as Structured Text (ST), PLCs are able to implement complex control logic, including safety mechanisms and fault handling procedures, which are critical to meeting the high safety standards and operating efficiency of elevator systems.

All in all, these components together form the basis of the elevator's electric drive system, and the performance and reliability of each component have a profound impact on the effectiveness, safety and economy of the entire system. Considering the interaction of these components and how they meet the specific needs of an elevator system is key to elevator system design and analysis.

Here are the specific models. All technical characteristics are presented at table 2.1-2.5 below. I used based on my design:

Table 2.1 Motor (Siemens 1LE0 Series)

manufacturer	Siemens
model	Siemens 1LE0 Series
power	3kW
Rotating speed	1500rpm
Voltage	400V
current	6.8A
efficiency	IE3
Protection level	IP55
Rotating speed	1500rpm
Voltage	400V
current	6.8A

Table 2.2 Gearbox selection

manufacturer	SEW-Eurodrive
model	SEW-Eurodrive R Series
type	Worm gear
gear ratio	50:01:00
efficiency	92%
Torque	300Nm
Backlash	Less than 5 arc minutes

Table 2.3 Frequency inverter selection

manufacturer	Danfoss
model	Danfoss VLT Series
Output Power	3kW
The output voltage	0-400V
control mode	V/F control, vector control
Communication Interface	RS-485, Modbus

Table 2.4 Position sensor (encoder) selection

manufacturer	SICK
model	SICK DFS60
type	Incremental
resolution	1024 pulses/rev
output signal	HTL
Supply voltage	10-30VDC

Table 2.5 Programmable Logic Controller (PLC) Selection

manufacturer	Schneider Electric
model	Modicon M241
CPU processing speed	100MHz
Memory	256 MB
I/O port	16 digital inputs, 16 digital outputs
Communication Interface	Ethernet, Modbus
Programming software	Support IEC 61131-3 (Codesys 3.x)

2.1.2 System analysis

In order for PLC to achieve the desired control effect of the system, in-depth research must be conducted when designing the control system. The control requirements for each type of electrical equipment are different and the process to be implemented by the equipment is different. Different requirements will be reflected in the quality of the product and the production efficiency of the product. In order to meet the effect in equipment control, certain restrictions must be placed on PLC, such as:

(1) When choosing a PLC, you must first consider that the model selection must be able to ensure its working requirements. At the same time, you must also consider the follow-up technical support after product production and the after-sales situation of the product. The principle of convenient after-sales should be used, and domestic products should be selected as much as possible. We have cooperated with companies that are relatively mature in product production and design, and selected mainstream models for corresponding control system research and design.

(2) Conduct more research activities to truly understand the types and methods of control systems needed in production and life. During development, it is necessary to fully listen to the suggestions of mechanical designers and operators and address their opinions.

(3) Considering the operating cost issue, after meeting the required control method, the simplicity, economy and convenience of maintenance of the product should be fully considered.

(4) In any control system, it must be considered that the equipment can operate reliably in a safe environment.

(5) When choosing a PLC for design, you must not only consider the current situation, but also consider future development, and leave interfaces in the system during design. Improving production efficiency and safety should be the top priority in design. However, as the times progress, the future development of the system also

needs to be considered. It is crucial to develop a system that is conducive to its future system improvement.

2.2 Elevator control system tasks and design solutions

2.2.1 Main contents of PLC control system design

The control system is mainly connected by the following three parts: PLC, input device, and output device. These three main parts are used to complete the control purpose to be achieved and some requirements for control. Therefore, when designing a PLC control system, you should consider:

(1) When designing the overall system, the requirements for production equipment and production processes, as well as the requirements for the control system and the economic budget for investment, should be considered.

(2) According to the control requirements, determine the digital I/O points and calculate the number of channels required for analog quantities. At the same time, allocate the specific functions of the I/O points and draw their usage resource diagram.

(3) Select an appropriate PLC to design the system. The quality of PLC is very important for this control system. Therefore, a suitable PLC must be selected for different control requirements. The PLC selected here is not the more expensive, the better, and its economy should be considered.

(4) At the same time, general electrical components should also be considered. For example, when selecting input devices, consider buttons, operating switches, limit switches, sensors, etc. When selecting output devices, consider the different choices of output objects that are more appropriate. Output equipment performs corresponding output, and the control objects include: motors, solenoid valves and other equipment.

(5) After everything is ready, perform key operations and write programs one by one. The program written here must be able to be recognized by the device and the

device can run the program. If the program is complex, the relevant description can be provided through a flow chart first. When faced with complex control programs, the task can be divided into several independent parts, and the complex control program programming can be divided into several small programs for design, which facilitates program programming and debugging. The process of programming is generally to first design a flow chart that meets the requirements, and then draw a ladder diagram. Because the control program is very important to the equipment, the writing of the control program requires repeated debugging and modification until the program meets the requirements and can run safely and stably.

2.2.2 Design requirements of control system

Elevators are becoming more and more intelligent, and the elevators manufactured by elevator manufacturers are becoming more and more intelligent. Customizing elevators according to consumer requirements is becoming more and more common. Because the design work time is limited, all control conditions cannot be satisfied, and only part of the function control is completed. like:

(1) Collective selection control. This kind of control analyzes and processes all external instructions in a unified manner to achieve a high degree of centralization. This processing method uses sequential processing. If the required running direction is inconsistent with the current running direction, no processing will be done.

(2) Downward selection. When calling the elevator from outside, the elevator can only move downward.

(3) Specific services. By design, specific floor services are provided for specific passengers and no calls are answered while the operation is running.

(4) Priority control of special floors. When a call appears on a specific floor, the call on the specific floor will be processed first, and other calls will not be processed first. After reaching the designated floor, the call on other floors will be processed.

(5) Elevator parking operation. During holidays, the elevator is turned off by a switch, so that the elevator stops at the designated floor, and all elevator equipment is turned off to save electricity.

(6) Full load control. If the elevator has reached rated load operation, no processing will be done temporarily for other calls.

(7) Clear invalid instructions. The elevator automatically recognizes whether the call received is consistent with the direction of travel. If it is inconsistent, it will not be processed.

(8) Automatic control of door opening time. According to the internal situation of the elevator and the call situation outside the hall, the car door adopts automatic control and automatically adjusts the opening time.

(9) Adaptive control of door opening time. Through sensing equipment, the real-time elevator passenger flow can be understood to minimize the door opening time.

(10) Open door time extension button. For some specific passengers, the door opening button needs to be set to extend the door opening time.

(11) Reopen the door if there is a fault. If the elevator cannot close the door during a malfunction, or passengers enter or exit during the closing process, the elevator door must be closed or opened again in a timely manner.

(12) Force the door to close. The compartment door is blocked and after the alarm is sounded, if there is any obstruction, the compartment door will be forcibly closed.

(13) Photoelectric device. Able to sense the entry and exit of relevant objects.

(14)Device. When entering and exiting the elevator, if there is still entry and exit when the door is closed, the door will be reopened.

(15) Assistant control box. When the passengers are crowded, a control box is designed on the left side of the car to facilitate passengers to control the elevator stop.

(16) Electronic touch button. Record the elevator operation status accordingly by pressing the keys.

(17) Lighting station announcement. The station announcement function is realized by controlling the lights outside the car. When the elevator arrives, the lights will flash and give voice prompts.

(18) Emergency operation. The elevator can be stopped in the event of a power outage by activating the backup power supply.

(19) Emergency operation in case of fire. When a fire occurs, the elevator will stop at the floor.

(20) Firefighting operations. After firefighters arrive, they can open the elevator door to rescue relevant personnel.

(21)Fault detection. When a fault occurs in the elevator that does not affect its use, the elevator fault is automatically recorded. The memory in the microcomputer can only store (8 to 20 faults). When the errors in the elevator reach a certain level, it will automatically report for repair and let the staff handle it.

2.2.3 Steps of PLC control system programming

Before designing a control system, what we have to do is to carefully analyze the control requirements of the system.

Only when the requirements are met can a reasonable and accurate design plan be formulated to achieve the specific requirements for control.

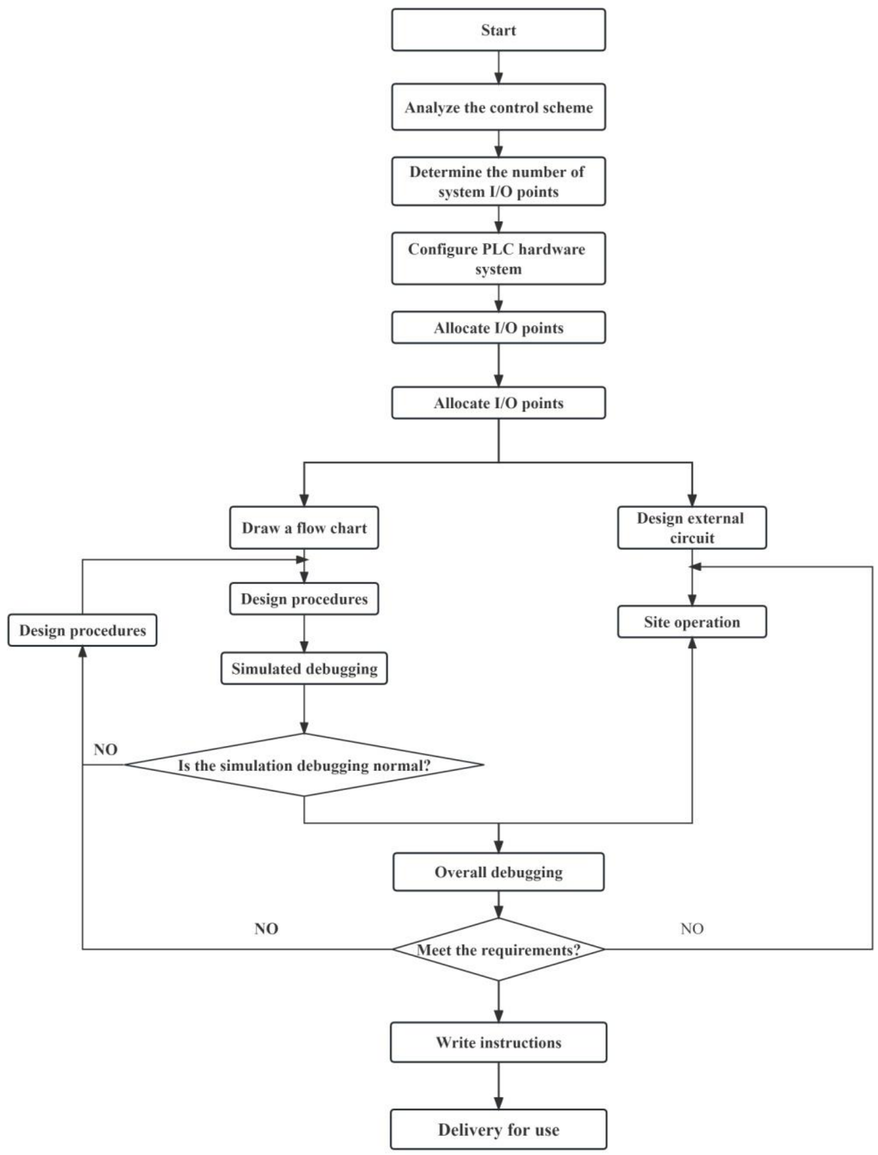

Figure 2.1 Design steps of PLC control system

The basic steps of PLC programming are:

(1) If the designed control system is complex, you first need to draw a flow chart of the system control (as shown in Figure 2.1). The sequence and conditions of the actions can be intuitively explained in the form of a flow chart. If it is a simple control system, the process of drawing graphics can be appropriately reduced.

(2) Design of ladder diagram. This is a critical step in the design of the entire program, and it is also the most difficult part of the entire program. Because a good design requires a certain amount of work experience, only the ladder diagram designed with corresponding experience can effectively meet the requirements.

(3) Edit the program based on the ladder diagram designed in (2).

(4) Input the program into the PLC so that the user can use it normally, and check it during the input process.

(5) Through debugging the program, make certain modifications to the program to make the program meet the requirements.

(6) Carry out relevant debugging according to the actual situation. Improve procedures, modify procedures that do not meet requirements, and check all

Connect lines until the requirements are met.

(7) Formulate technical documents.

(8) Delivery for use.

2.3 Basic control principle of PID algorithm

PID (Proportional Integral Differential), as a closed-loop control algorithm, is a classic algorithm among control algorithms. In a continuous program, this control method is more convenient to implement because of its mature technology and subsequent support. PID adjustment realizes the control function by adjusting the size of the input value deviation. This control method generally uses differential, Integral, proportion and other functions are used to perform calculations and realize control functions.

PLC (programmable logic control device), as a new industrial automatic control equipment in modern industry, has been widely used in production, scientific research, social life and other aspects. Some large PLCs have been equipped with functional modules with process automatic control. This module can perform closed-loop automatic control of up to dozens of analog quantities, but the cost of this module is relatively high. Under normal circumstances, the closed-loop automatic control of the automatic control system composed of small and medium-sized PLC devices we use only needs to be performed on a single or several channels of analog quantities. The hardware requirements are not high. You only need to find a device in the hardware that can convert digital signals and analog signals to each other. The principle of PID controller is shown in Figure 2.2:

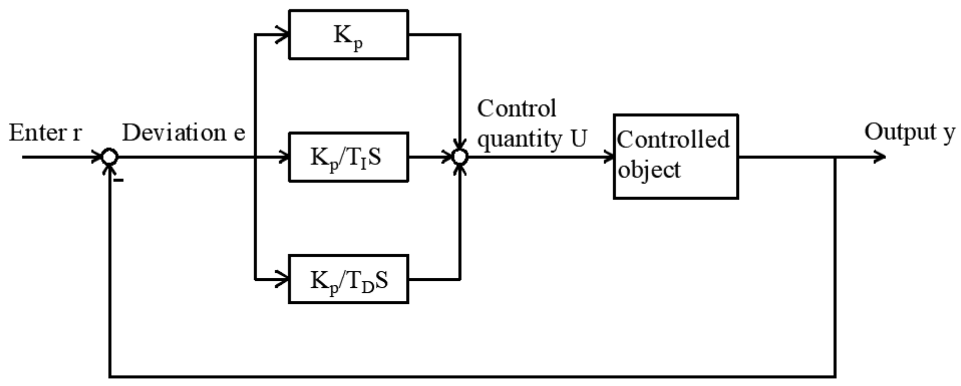

Figure 2.2 PID controller schematic diagram

(1) Proportional control

Regarding the definition of proportional control: During the signal sending and receiving process, if the amount of signal deviation is within a certain ratio, these errors will be received and controlled by the proportional controller. In this way, PID can reduce the error, so as a proportional control The key - proportional coefficient Kp is very important. There are also some shortcomings in proportional control: For some equipment, which has a self-balancing function, a certain static difference may occur under proportional control. To reduce the static error, it is generally necessary to increase the I seal. However, if Kp is adjusted too large during the process, it will destroy the dynamic performance of the system and increase the overshoot of the system.

(2)Integral control

Control by memorizing and integrating calculated errors is integral control, which can eliminate static errors to a certain extent. However, the main shortcomings of this kind of control are: because of the hysteresis characteristics of the integral itself, if the integral effect is too strong, it will affect the dynamic quality of the controlled object, and it is also detrimental to the stability of the closed-loop system.

(3) Differential control

To analyze the change of error, it is necessary to differentiate the error, so that its change form can be obtained. The advantage of differential control is mainly to speed up the response time of the system, so that the system overshoot can be reduced to a certain extent. However, differential control also has its shortcomings: when encountering interference, the control system may cause certain errors. Depending on the equipment being controlled, in order to improve system reliability, the control parameters in PID can be adjusted to achieve the desired effect. Because the algorithm of differential control is relatively simple and the parameters are easy to adjust. Not only that, but the advantage of differential control is its high accuracy, so this kind of control is widely used.

PID control is linear control, and control is realized based on the comparison between the actual value C(t) and the given value R(t):

$$E(t) = R(t) - C(t) \tag{2.1}$$

The equipment is controlled by performing some proportional transformation, integral transformation, or differential transformation on the deviation. The rules are as follows:

$$U(t) = K_p\left[E(t) + \frac{1}{T_i}\int_0^t E(t)dt + \frac{TddE(t)}{dt}\right] \tag{2.2}$$

In the above formula: Kp: proportional coefficient of the controller; $\frac{1}{Ti}$: Integral constant of the controller; Td : Controller differential constant; $E(t)$: The difference between the system given value and the actual value; *U(t)*: The output of the controller.

Equation 2.2 is a mathematical expression of continuous analog quantity. For PLC users, the PLC program can only to operate discrete digital quantities, in order to be able to use calculation tools to perform calculations, it must be converted into a difference equation for calculation.

Let $U(t) \approx U(kt), E(t) \approx E(kt)$,then

$$\int_0^t E(t)dtT \approx \sum_{j=0}^{k} E(jt) \tag{2.3}$$

$$\frac{dE(t)}{dt} \approx \frac{E(kt) - E(k-1)t}{T} \tag{2.4}$$

Through transformation, the algorithm of digital PID control can be obtained:

$$U(K) = Kp\sum_{j=0}^{k} E(j) + K_d\left[E(K) - E(K-1)\right] \tag{2.5}$$

In the above formula: K_p: proportional gain coefficient; T: system sampling period; $K_d=K_pT_d/T$: differential coefficient; $Ki=K_pT/T_i$: integral coefficient; $U(K)$: Abbreviation of $E(KT)$.

The deviations are added and calculated through operation, and then the position control variable is obtained. Integration via PID algorithm

If superimposed, the system may experience data overflow, which is not allowed.

Not hard to get next equation:

$$U(K-1) = K_pE(K-1) + K_i\sum_{j=0}^{K-1} E(j) + K_d\left[E(K-1) - E(K-2)\right] \tag{2.6}$$

The incremental control algorithm is obtained by subtracting Equation 2.5 from Equation 2.4:

$$\begin{aligned} &U(K) = U(K) - U(K-1) \\ &= (K_p + K_i + K_d)E(K) - (K_p + 2K_d)E(K-1) + K_dE(K-2) \end{aligned} \tag{2.7}$$

The system block diagram of PID is shown in Figure 2.3.

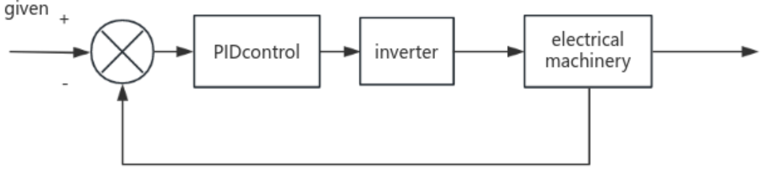

Figure 2.3 PID control system block diagram

CHAPTER 3. SYNTHESIS OF A ROBUST POSITIONING CONTROL SYSTEM AND ITS RESEARCH USING MATHEMATICAL MODELING

3.1 Obtain the structural diagram of the position electric drive system and its MATLAB model

First of all, it should be defined reasons of oscillations appear in position electric drive system. We should investigate causes of self-oscillations in a positional electric drive in the presence of backlash using Goldfarb method using hodograph.

While we have significant nonlinearity at control loop, we can obtain:

$$W_{linear}\left(j\omega\right) = -\frac{1}{W_{nonlinear}\left(j\omega\right)} . \tag{3.1}$$

The frequency transfer function of the nonlinear link has the following form

$$W_{nonlinear} = q\left(a\right) + jq'\left(a\right), \tag{3.2}$$

where $q\left(a\right) = \frac{4c}{\pi a}\sqrt{1-\left(\frac{b}{a}\right)^2}$, $q'\left(a\right) = -\frac{4cb}{\pi a^2}$ - coefficient of harmonics linearization.

The hodograph of a nonlinear link is determined by the expression:

$$-Z\left(a\right) = -\frac{1}{W_H\left(a\right)} = -\frac{1}{q\left(a\right) - jq'\left(a\right)} = -\frac{q\left(a\right) + jq'\left(a\right)}{q^2\left(a\right) + q'^2\left(a\right)} = -\frac{\frac{4c}{\pi a^2}\left(\sqrt{a^2-b^2} + jb\right)}{\left(\frac{4c}{\pi a^2}\right)^2\left(a^2-b^2+b^2\right)} \tag{3.3}$$

Now, we obtain $Z\left(a\right) = -\frac{1}{W_H\left(a\right)} = -\frac{\pi}{4c}\left(\sqrt{a^2-b^2} + jb\right)$.

Amplitude-phase characteristic of the linear part $W_{linear}\left(j\omega\right) = \frac{K_{obj}}{T^2(j\omega) + j\omega}$ connection of aperiodic and integrating links.

That is why hodograph of Goldfarb takes place, presented at figure 3.1.

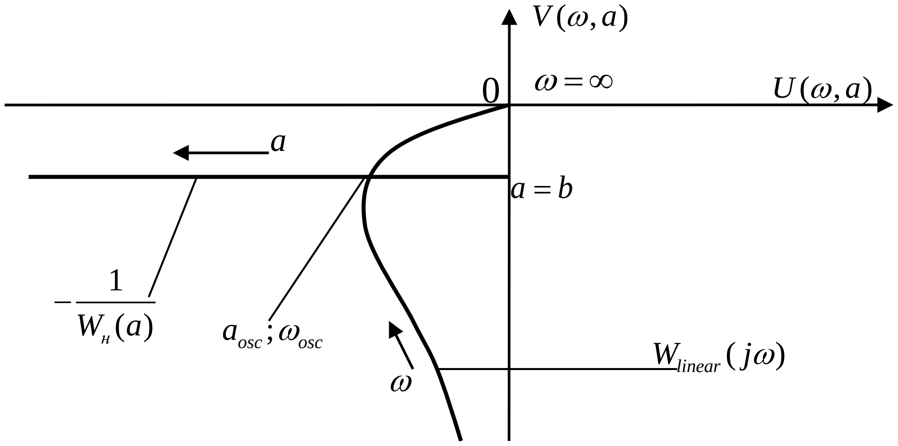

Fig.3.1. Hodograph of Goldfarb.

If we have speed feedback, we obtain another type of hodograph, like presented at figure 3.2.

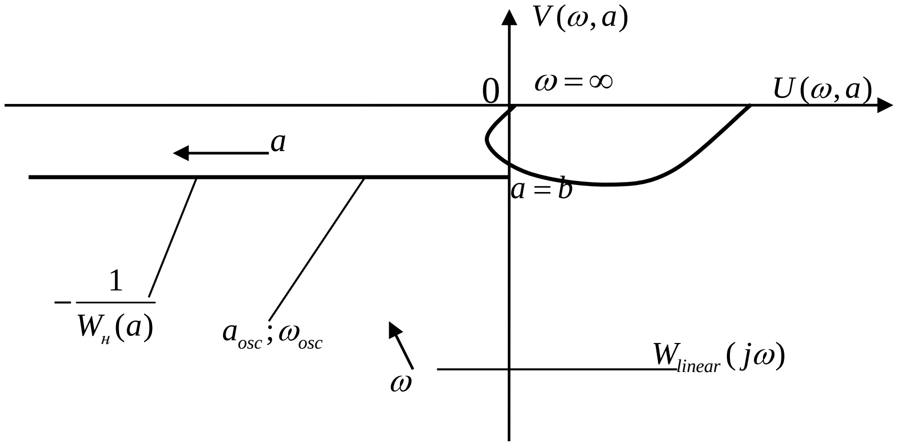

Fig.3.2. Hodograph of Goldfarb using speed feedback.

However, due to the fact that an external shaft position encoder cannot be used for speed feedback, such a hodograph is unattainable and the system will experience oscillations when using proportional linear controllers. The amplitude and frequency of oscillations will vary depending on the system parameters.

As a result, we get steady self-oscillations in the circuit as $-\frac{1}{W_{nonlinear}(a)}$ goes from the inside to the outside relative to the amplitude-phase characteristic of the linear part of the system. It is possible to perform an analytical solution using the Goldfarb equation.

Now we focus on building and analyzing a model of a positional electric drive system with output coordinate control. Key components of the system include a three-phase induction motor, worm gearbox, frequency converter, position sensor (encoder) and programmable logic controller (PLC). The mathematical model of each component is carefully designed to reflect its actual role and performance in the system.

The electric machine is modeled based on its electrical and mechanical characteristics, taking into account its torque-speed relationship and dynamic response. The gearbox model simulates its reduction ratio and torque conversion characteristics, especially taking into account the impact of backlash on power transmission. The key to the frequency converter model is its ability to regulate motor input voltage and frequency to accurately control motor speed. The position sensor (encoder) model ensures accurate feedback of the elevator position and is crucial to the accuracy of the system.

One of the approaches of increasing quality of system is the use of an adaptive component of the reference model, which provides robustness of system to existing nonlinearities. A typical scheme of such control is presented in figure 3.3.

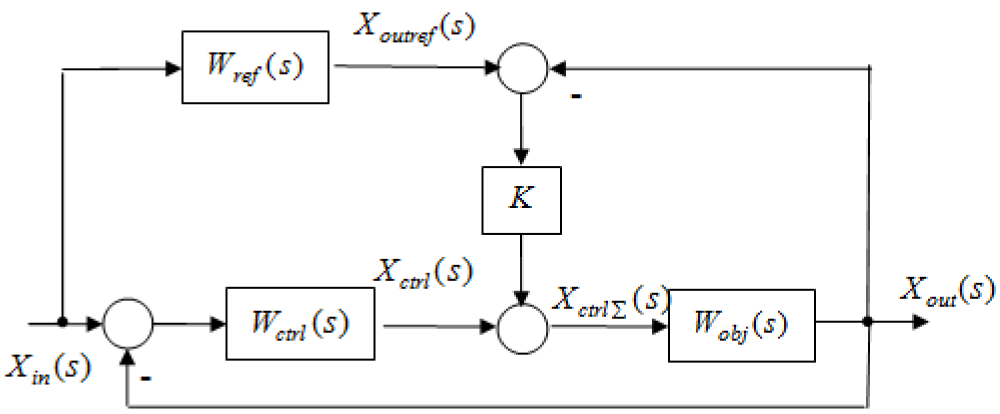

Fig.3.3. Block diagram of the mathematical model of the position electric drive

$W_{ctrl}(s)$ - transfer function of the position controller, for example PI-regulator; $W_{obj}(s)$ - transfer function of the regulated object; $W_{ref}(s)$ - transfer function of the reference mathematical model of the position control loop; K - gain of the mismatch signal between the reference and current movements; $X_{in}(s)$ - setting position values determined by the motion profile; $X_{out}(s)$ - current position; $X_{outref}(s)$ - reference position; $X_{ctrl}(s)$ - signal at the output of the position controller without taking into account correction; $X_{ctrl\Sigma}(s)$ - signal at the output of the position controller taking into account the correction.

This elevator control system model is mainly used to describe the motion control process of the elevator, which contains some key components and control strategies. Here is an explanation and overall significance of each part of the model:

Setpoint Position: The target position of the elevator. By setting the desired position, the user hopes that the elevator can accurately reach the position.

Desired Model: Describes the response of the elevator system to a set position. The parameters of this model, such as the proportional term (K) and the time constant (Tp), determine the dynamic characteristics of the elevator system. By adjusting these parameters, the response speed and stability of the elevator to position setting changes can be changed.

Regulator: A PID (proportional-integral-derivative) or PI (proportional-integral) controller is used to adjust the elevator drive system based on the error between the actual position and the desired position. This ensures that the elevator can respond quickly and accurately to the position set by the user, and has a certain degree of stability against external disturbances.

IM Model (gearbox model): Considers the gearbox model in the elevator drive system. The gearbox introduces backlash, which is caused by some delay or "play" in the mechanical transmission. Modeling the system taking into account the return clearance helps to describe the dynamics of the elevator motion more accurately.

1/S Backlash Actual Position: A 1/S transfer function is introduced to simulate the effect of backlash. This transfer function represents the effect of backlash on actual position feedback.

Overall, this model is used to describe the control process of the elevator system, taking into account the desired position setting, actual position feedback, the regulator, and the backlash in the mechanical transmission system. By adjusting the parameters and control strategies of the model , the performance of the elevator can be optimized, improving its robustness to desired position changes and external disturbances, and ensuring that the elevator can operate smoothly and accurately under various operating conditions.

1. Desired position setting

The desired position setting is the target position set by the user through the elevator control system. In a mathematical model, we can use ($r(t)$) to represent the function of the desired position, where (t) is time. The desired position can be a fixed value or a time-varying signal.

2. Mechanical transmission system return clearance model

Mechanical transmission systems in elevator systems introduce backlash, which is a delay caused by slippage or play between transmission elements. The return gap can be expressed as a transfer function:

$$G(s) = \frac{1}{Ts + 1} \qquad (3.4)$$

Among them, (s) is a complex variable and (T) is the time constant of the return gap. This transfer function describes the effect of backlash on actual position.

3. PID/PI regulator

When controlling the elevator system, we use PID (Proportional-Integral-Derivative) or PI (Proportional-Integral) regulator. The transfer function of the PID controller is:

$$C(s) = Kp + \frac{Ki}{s} + Kd\, s \qquad (3.5)$$

Among them, (Kp), (Ki) and (Kd) are proportional, integral and differential gains respectively. The PI controller is a special case of PID, that is ($Kd = 0$).

4. Transfer function of the overall elevator system

Integrating the desired position setting, return clearance model and regulator, the transfer function of the overall elevator system can be expressed as:

$$H(s) = \frac{C(s)G(s)}{1 + C(s)G(s)} \tag{3.6}$$

This transfer function describes the relationship between the input (desired position) and the output (actual position) of the elevator system.

Model parameter selection explained

1. Desired position setting

The parameters for desired position setting are usually determined by the design requirements of the elevator system and user needs. For example, if the elevator is required to respond quickly to changes in desired position, the desired position setting signal may contain higher frequency components.

2. Mechanical transmission system return clearance model

The time constant (T) of the return gap reflects the delay in the response of the return gap to the actual position. A smaller (T) value means that the backlash affects the actual position more quickly, while a larger (T) value means that the backlash affects the actual position more slowly.

3. PID/PI regulator

The parameter selection of the PID/PI regulator involves a balance between the stability, transition characteristics and anti-interference ability of the system. Generally speaking:

- (Kp) controls the speed of response, increasing it can improve the sensitivity of the system.

- (Ki) The integral part of the control system used to eliminate steady-state errors.

- (Kd) controls the differential part of the system, helping to suppress oscillations and improve system stability.

Combining these models, we built the structure diagram of the system in the Simulink environment of MATLAB. In this diagram, the motor, gearbox, frequency converter, encoder and PLC are represented as interconnected modules, each with detailed parameter configuration to simulate actual operating conditions. The motor output is connected to a gearbox, which in turn transmits power to the elevator car, while an encoder provides feedback on the car's position. All this information is fed back to the PLC, which runs advanced control algorithms (such as PID controllers) to ensure that the elevator reaches the predetermined floor accurately.

Transfer function of the system, according rules, of structure scheme transforming, will be written:

$$W_{sys}(p) = \frac{X_{out}(s)}{X_{in}(s)} = \frac{W_{ctrl}(s) + W_{obj}(s)\cdot K\cdot W_{ref}(s)}{1 + W_{obj}(s)\cdot K + W_{ctrl}(s)} \tag{3.6}$$

From the obtained expression, it is obvious that $W_{sys}(s) \to W_{ref}(s)$ at $K \to \infty$. At practice value of gain K should be limited due to influence of disturbances, which take place at agricultural machinery.

3.2 Investigation of position electric drive using robust controller by numerical modeling.

Advantages of proposed regulator using numerical modeling was investigated. At figure 3.4 shown transients of position using sinus setpoint adjuster (curve 1) and actual position using PI – regulator (curve 2) and robust regulator component (curve 3). In this case we used model of electric drive that is fully correspond to model, which presented at previous scheme. We could see that using of robust component allows significantly remove influence of backlash. In this case simplified model of electrical drive was used.

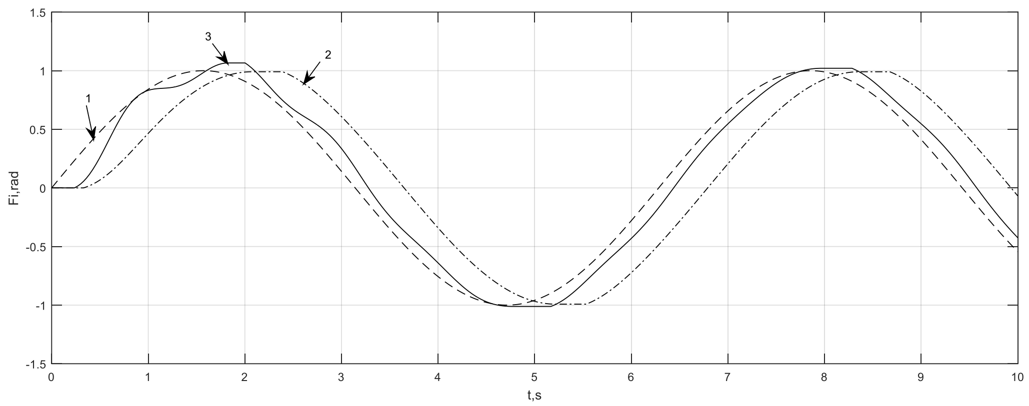

Fig.3.4. Transients of setpoint position signal and actual positions using different types of regulators.

As an input signal of this scheme sinus wave signal was used. But for the reasons of accurate investigation of dynamic of electric drive, full model of induction motor should be used. For this purposes expended model of electric drive was developed. The view of numerical scheme, developed in MATLAB Simulink presented at figure 3.5. We use AC3 typical model of “frequency inverter – induction motor” system from MATLAB and add components for realization of position control loop.

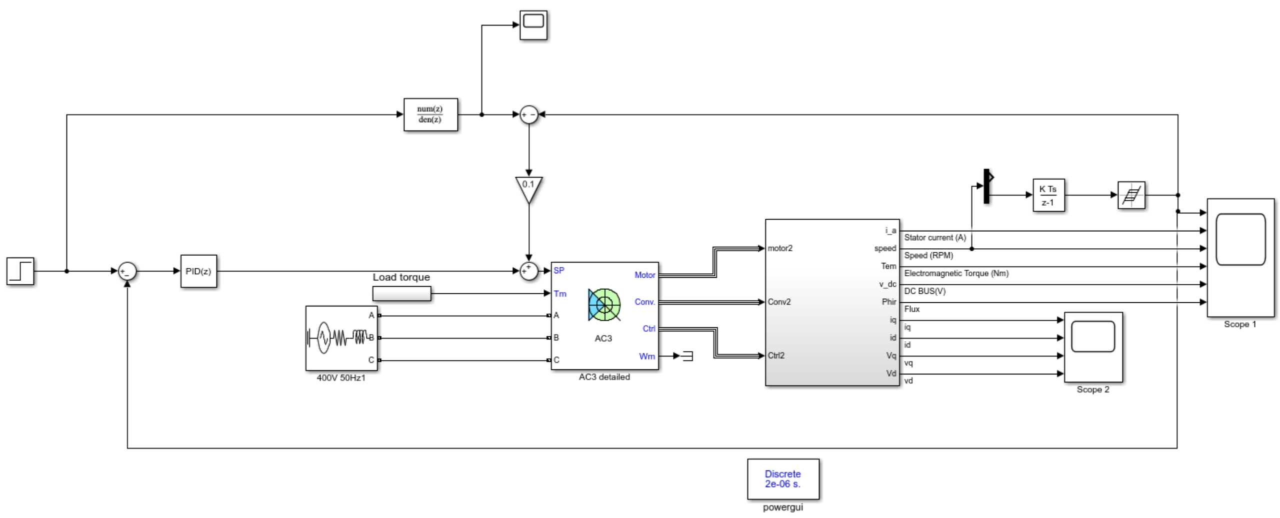

Fig.3.5. Mathematic model of position electric drive with induction motor and backlash.

Let us make an adjustment of PID regulator of position. For this purpose we use block Check Step Responce characteristics, which defines transients according to limits at graph.

For adjustment we use parameters of PID -regulator of position, starting from Kpr=1; Kint=0; Kdif=0.

After this we adjust possible boundaries at next window, presented at figure 3.6.

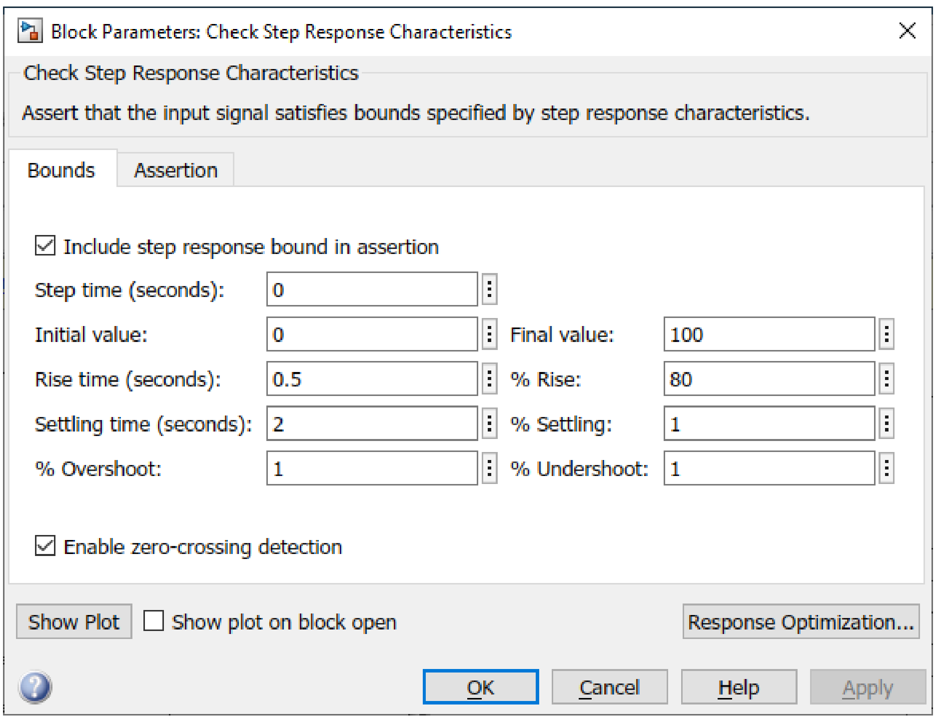

Fig.3.6. Window of boundaries adjustment.

We obtain opening procedure of graph boundaries, as presented at figure 3.7.

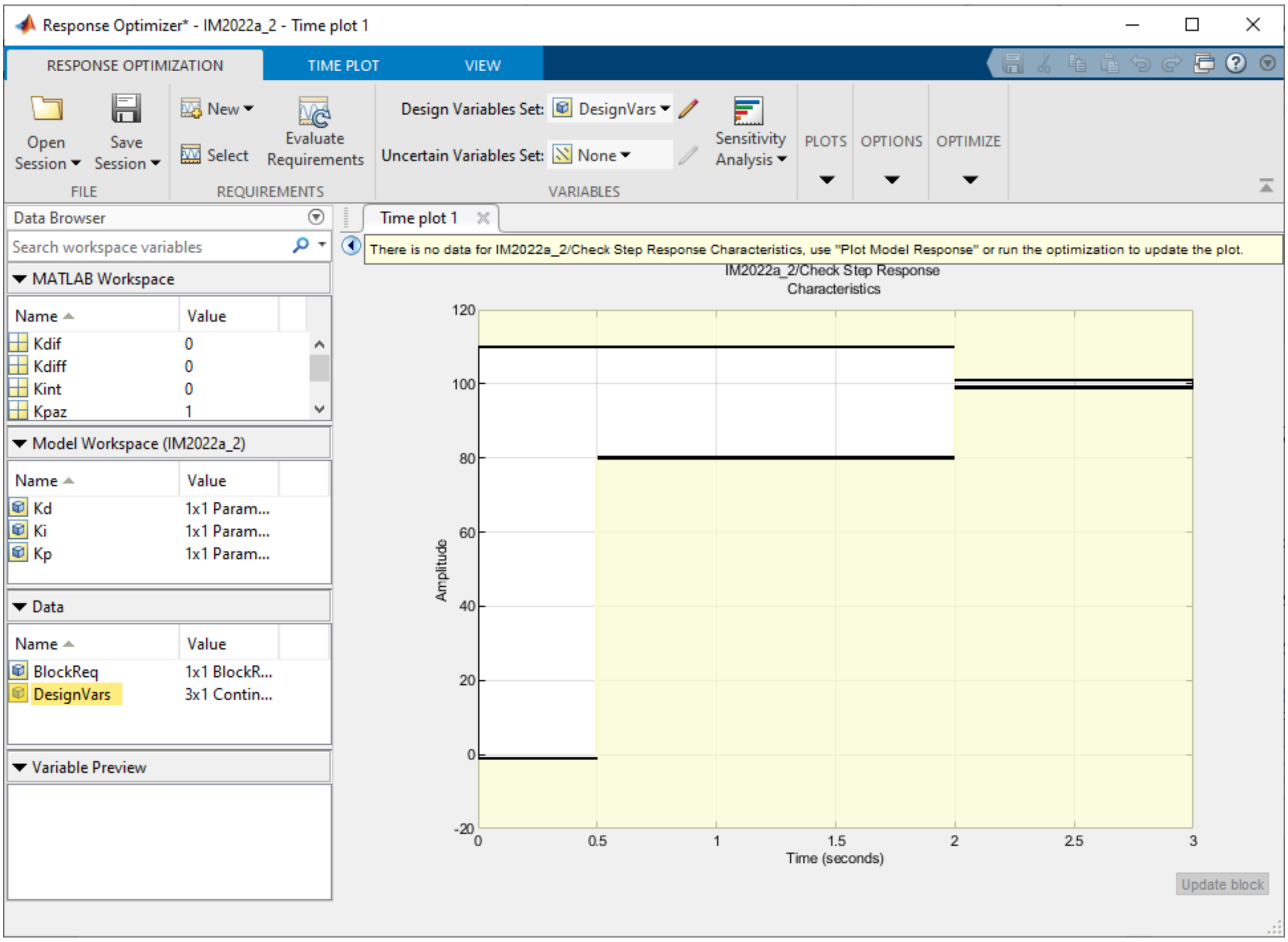

Fig.3.7. Transient position boundaries.

After this procedure we click button “response_optimization”, choose parameters for optimizing procedure, like presented at figure 3.8.

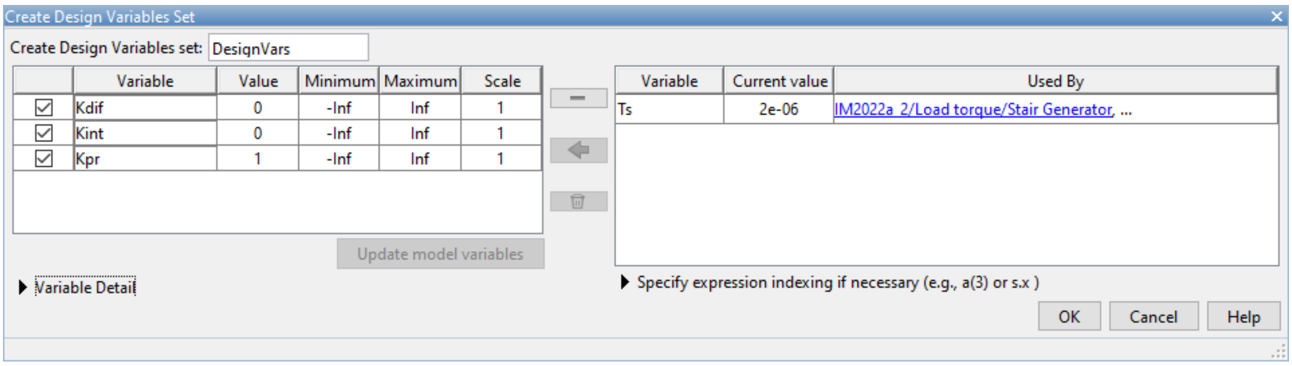

Fig.3.8. Parameters for optimization.

After this we click “Optimize” and start procedure of optimization. We obtain consequent procedure of iteration to obtain good behavior of transients, as presented at figure 3.9.

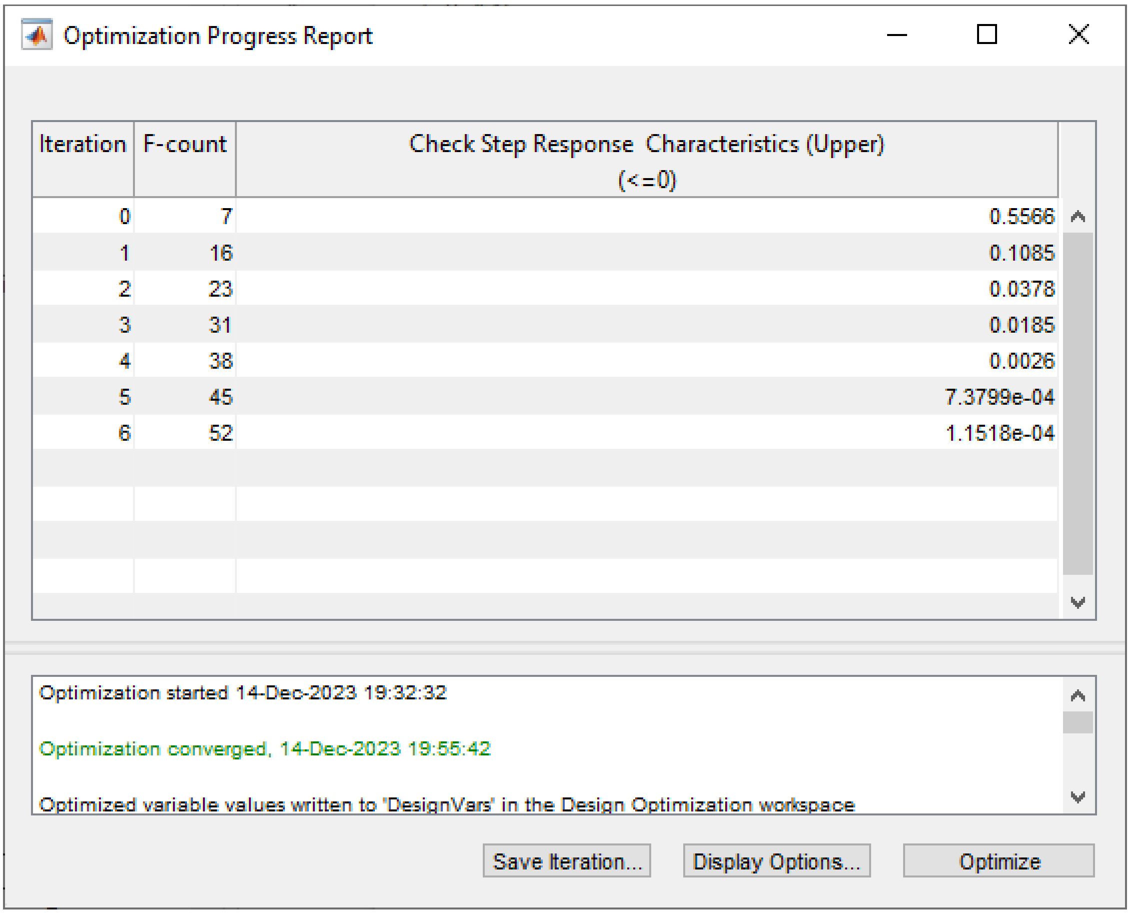

Fig.3.9. Iteration steps of optimization.

After this we obtain next visualization of iterations of optimization procedure, as presented at figure 3.10.

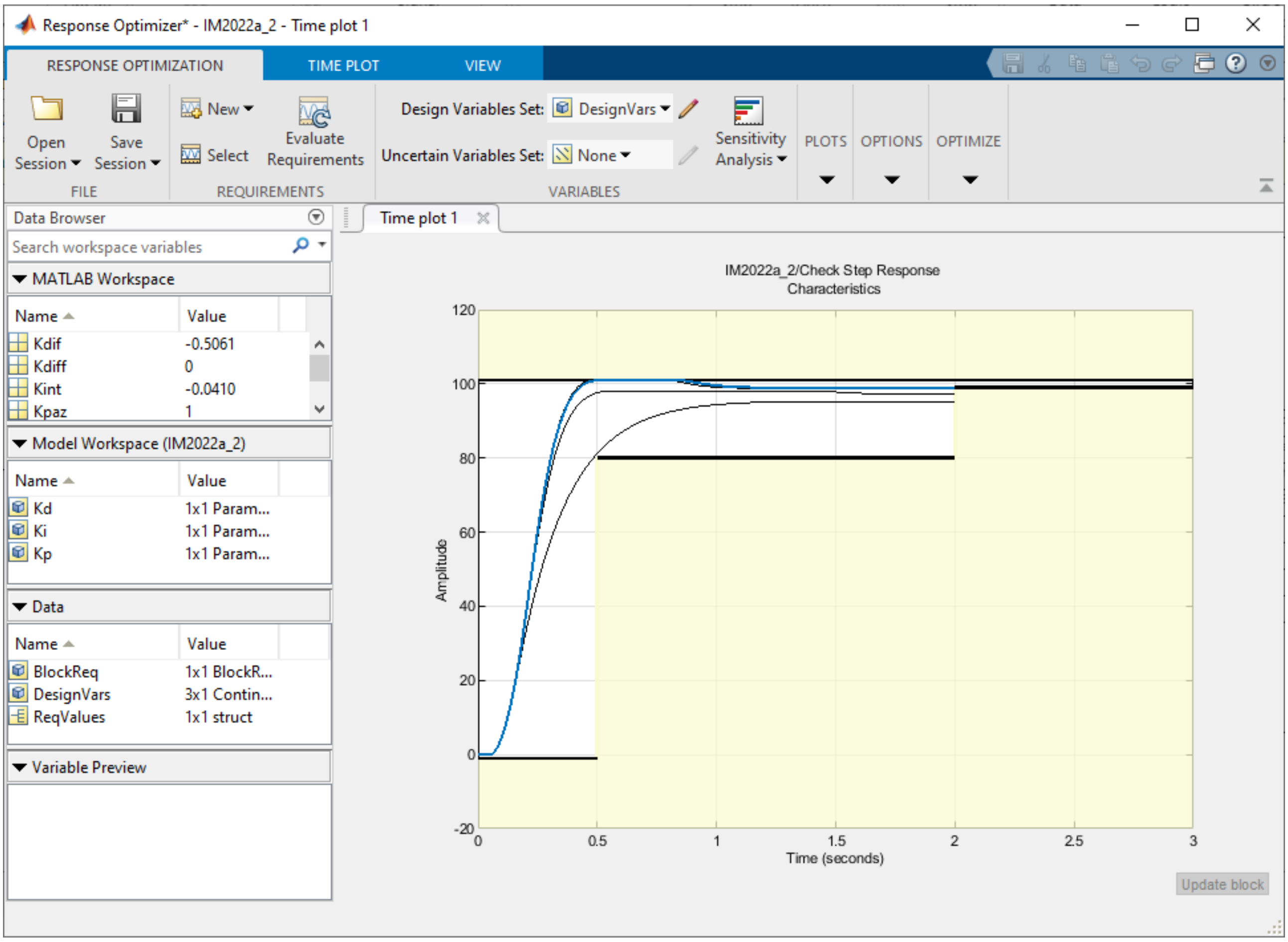

Fig.3.10. Step reaction at different optimization iterations.

Using this parameters and correction gain could be obtained transients, presented at figure 3.11.

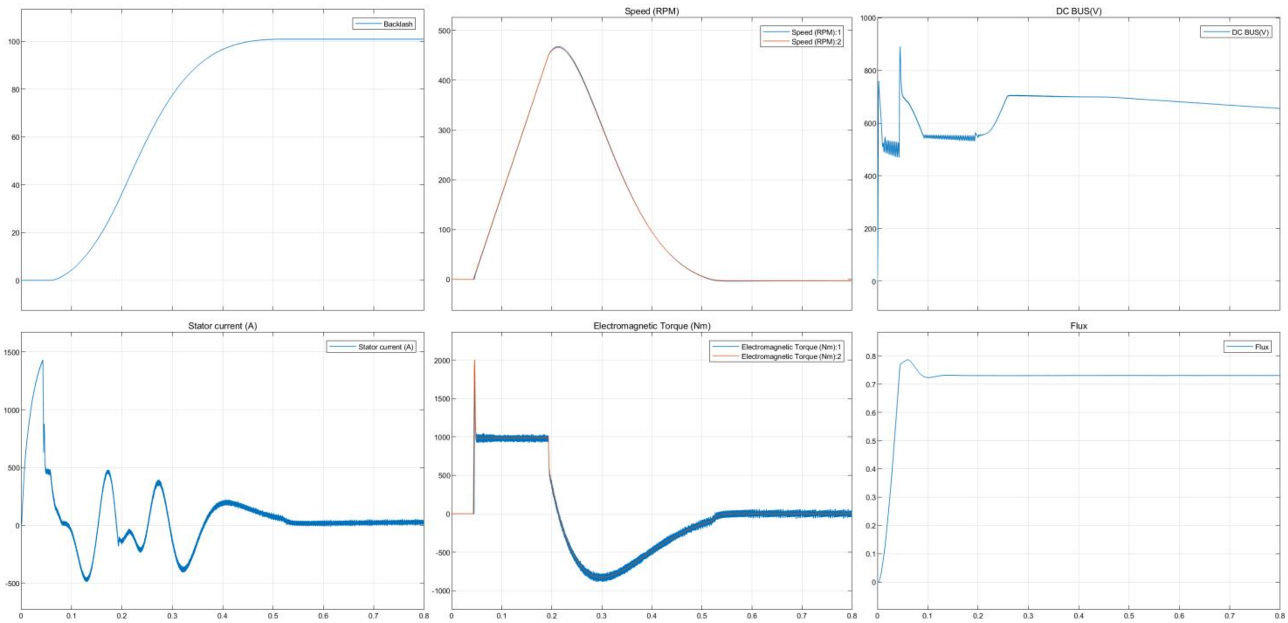

Fig.3.11. Transients with compensation.

Conponents of currents have form, presented at figure 3.12.

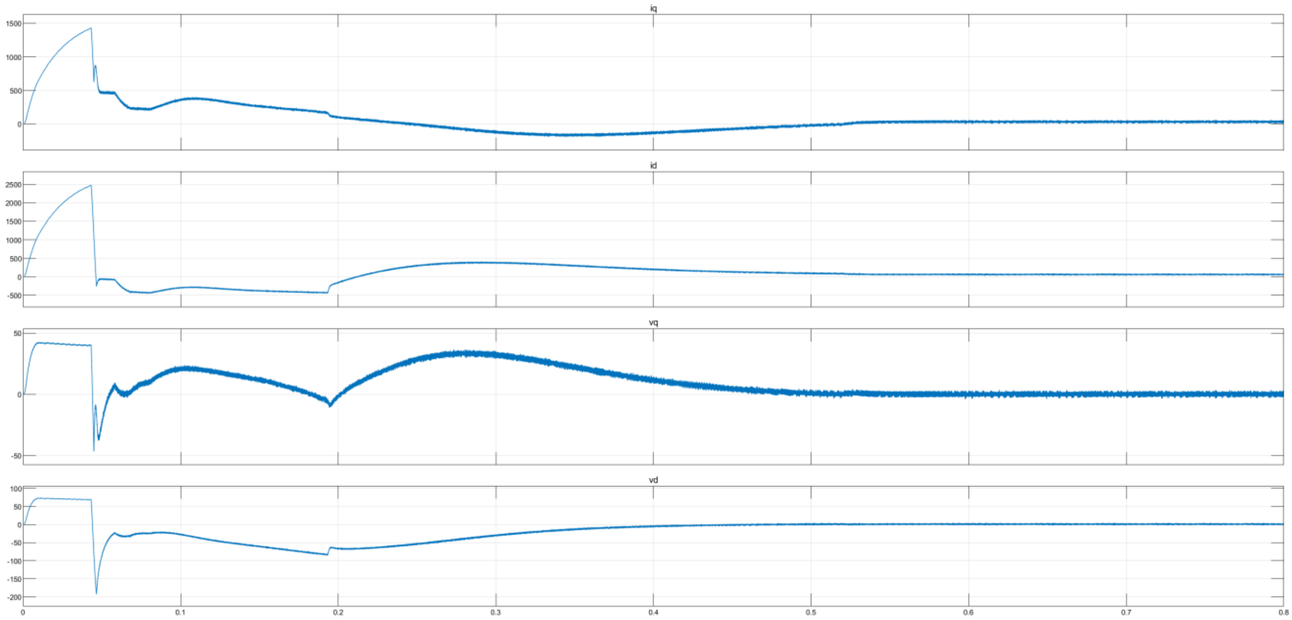

Fig.3.12. Components of current

Using robust regulator we obtain transients, presented at figure 3.13.

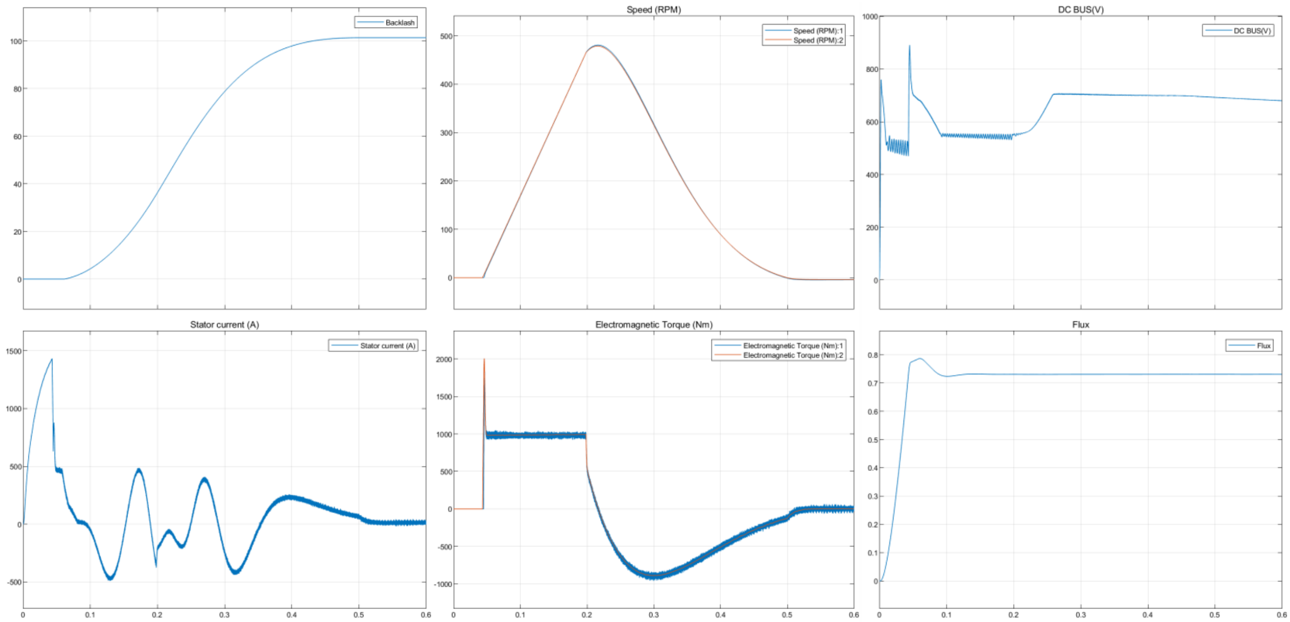

Fig.3.13. Transients using robust control.

3.3 Practice realization of proposed robust control

Program realization of robust control using ST language in Codesys 2.3. is presented at figure 3.14. Also it is realized mathematical model of positioning drive and visualization process.

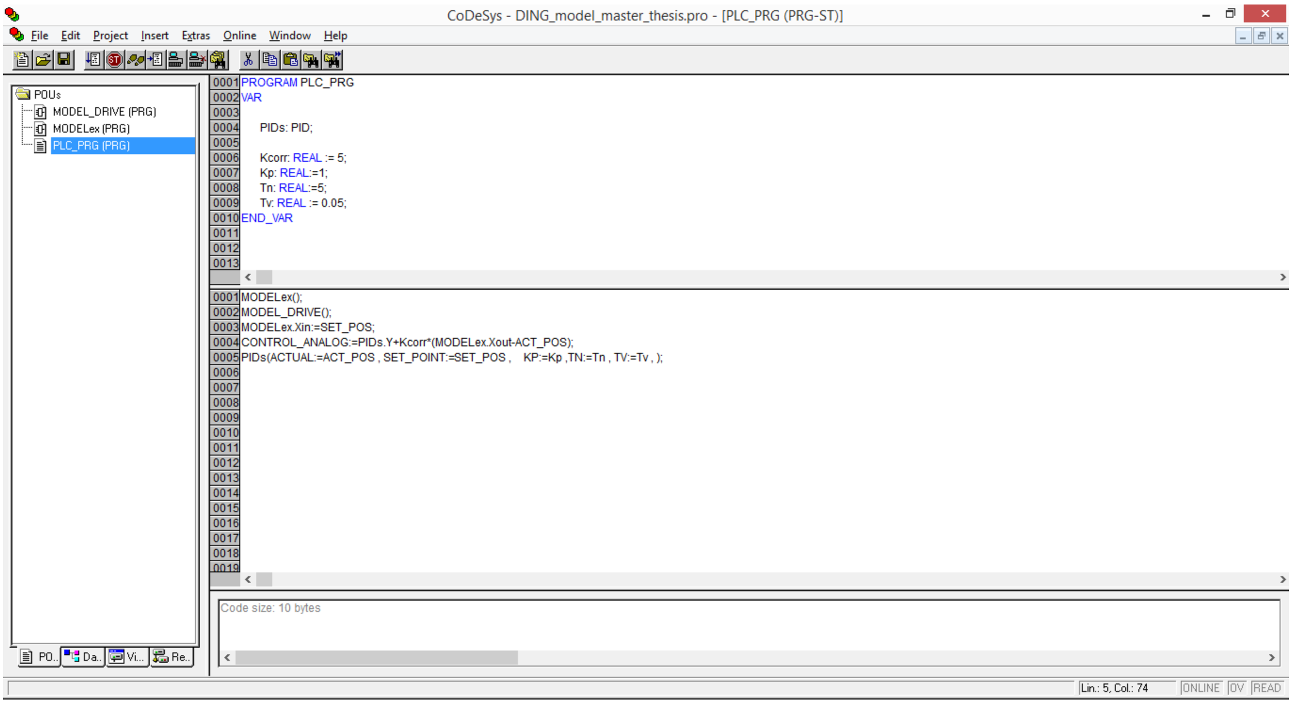

Fig.3.14 Practical realization of controller.

At this form we use PID –regulator from Codesys Util.lib library, which allows to obtain good characteristics. Values of gain are assigned manually but good behavior of transients could be achieved.

Dynamics of electric drive is very complicate to make in Codesys 2.3, so it was made using functional block language in the form of aperiodic link, as it shown at figure 3.15.

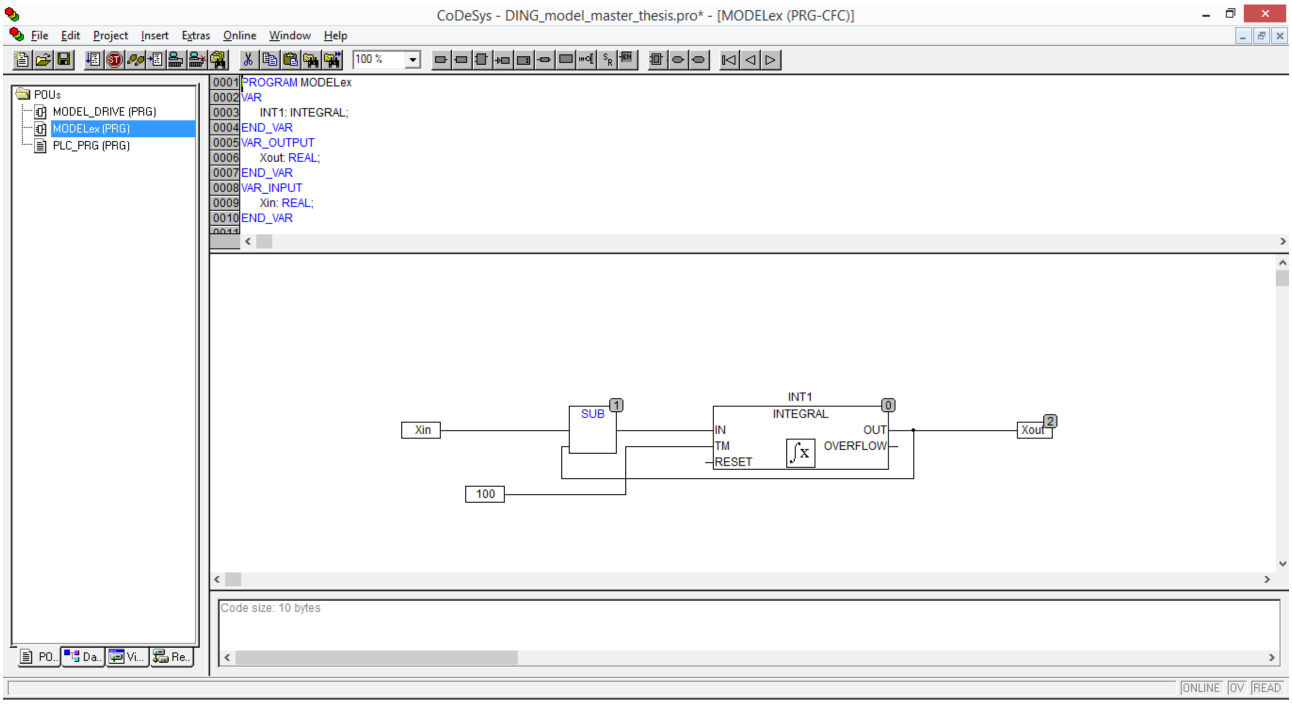

Fig.3.15. Electric drive simplified model

Transient of position of output shaft using Codesys 2.3 internal block realization is presented at figure 3.16.

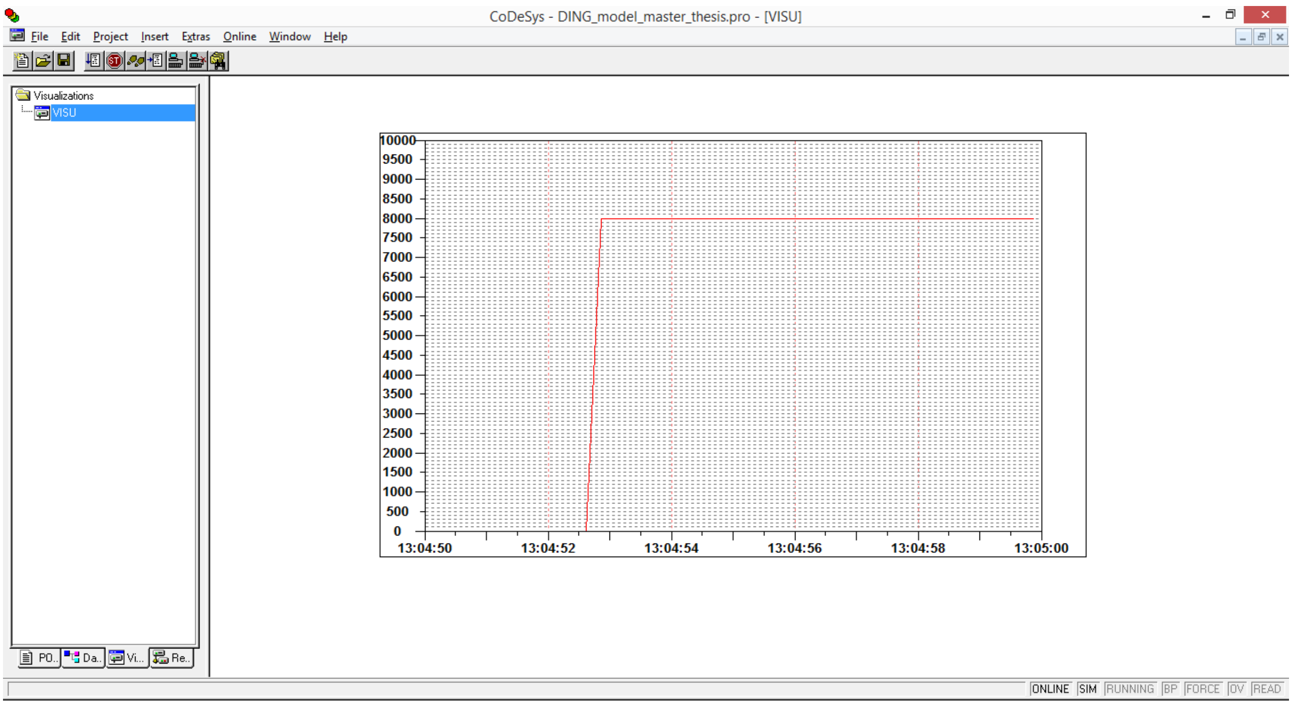

Fig. 3.16. Visualization screen at Codesys 2.3.

Vertical axis has dimensions in output pulses of encoder and not depends from meters or millimeters.

It should be noted that the use of a robust regulator does not require a significant complication of the control algorithm compared to a typical regulator, which will not lead to overloading the PLC program.

Also, the proposed regulator can be implemented in the form of a separate block with the possibility of sub-setting, which will simplify its practical use.

CHAPTER 4 STARTUP PROJECT

4.1 Goals and Stages of Implementation of the Control System

The purpose of this chapter is to establish and substantiate the structure and functions of the robust positioning control system. This system, distinguished by its innovative use of advanced control algorithms, aims to enhance precision and reliability beyond current market offerings. The novel feature of this system is the integration of sophisticated feedback mechanisms, which significantly reduce error margins and improve overall system responsiveness. The commencement of this project necessitates a detailed outline of the goals at each stage of development, as summarized in Table 4.1.

Table 4.1 - Goals of Phased Implementation of the Control System

Stages of Control System Implementation	Phased Implementation Goals of the Control System
Preliminary Stage	Analysis of user requirements and shortcomings of existing systems.
Innovation and Novelty	Development of advanced algorithms and technology to surpass existing systems.
Market Analysis	Review and identification of competing technologies in the market, conducting comparative technical and economic analyses.
Resource Allocation	Determination of necessary resources such as materials, labor, and technology for effective implementation.
Financial Planning	Estimating the costs and pricing strategy for the new system.
Investment Phase	Exploring investment opportunities and securing necessary funding.
Marketing and Sales	Establishing sales channels, attracting potential users, and segmenting the market effectively.

4.2 Justification of Relevance and Recognition of an Innovative Idea for the Control System Project

The development of this control system project is based on the information and research findings presented in the previous chapters, which highlighted the limitations and deficiencies of existing control systems in similar applications. Recognizing new needs in precision control and efficiency, particularly in critical applications like automation and robotics, this project proposes an innovative solution that is more advanced and effective than current offerings.

The proposed control system stands out by offering unparalleled precision and adaptability, making it highly suitable for applications where traditional systems fall short. The reflection on the problems identified in existing systems substantiates the necessity and feasibility of this innovative solution. Table 4.2 outlines the relevance and novelty of this control system idea, detailing its application directions and benefits for users.

The Content of the Idea	**Application Directions**	**Benefits for the User**
Advanced control algorithms for precision and reliability	Automation, Robotics, Industrial Processes	Enhanced accuracy, reduced operational errors, and improved system responsiveness
Integration of adaptive feedback mechanisms	Aerospace, Manufacturing, Medical Devices	Increased system adaptability to changing conditions, higher precision in complex environments
Energy-efficient and scalable design	Energy Management, Smart Systems, Consumer Electronics	Lower energy consumption, adaptability to various scales and applications, user-friendly interfaces

Table 4.2 - Relevance and Novelty of the Control System Project Idea

4.3 Analysis of the Competitive Environment

The competitive landscape for positioning control systems is dynamic and challenging. Our system, as detailed in Chapter 3, brings several innovative features to the table, making it crucial to analyze its position against competitors. We start by comparing our system with a leading market competitor, focusing on key technical and economic aspects.

Table 4.3 - Technical and Economic Advantages

No.	**Technical and Economic Characteristics**	**Our Positioning Control System**	**Nearest Market Competitor**
1	Precision and Reliability	Superior accuracy with advanced control algorithms	Basic precision capabilities
2	Adaptability	High adaptability to diverse operational environments	Limited adaptability
3	Energy Efficiency	Optimized for reduced energy consumption	Relatively higher energy consumption
4	User Interface	Intuitive and user-friendly design	More complex user interface

To better strategize and navigate this competitive space, a detailed SWOT analysis was carried out.

Table 4.4 - Expanded SWOT Analysis

Factors	Our Positioning Control System Assessment
Strengths	- Cutting-edge technology incorporating latest advancements. - High precision and reliability exceeding industry standards. - User-friendly interface enhancing user experience. - Robust design suitable for various industrial applications.
Weaknesses	- Higher initial development and production costs. - Requires specialized training for optimal operation. - Dependency on specific high-end components for manufacturing.
Opportunities	- Expanding market demand in automation and precision engineering. - Potential for strategic partnerships with industrial giants. - Scope for diversification into related fields like robotics and smart manufacturing. - Opportunities for global expansion, especially in emerging markets.
Threats	- Rapid advancements in technology by competitors. - Market volatility and changing industry regulations. - Potential for price undercutting by competitors with cheaper alternatives. - Risk of technological obsolescence due to fast-paced innovation.

The findings from this SWOT analysis underscore the need for a strategic approach that leverages our strengths, such as advanced technology and precision, while addressing weaknesses like higher costs and training requirements. The opportunities for market expansion and partnerships are promising, but we must remain vigilant of the threats posed by rapid technological change and competitive pressures.

4.4 Justification of Resource Provision of the Project

In this section, we delineate the various resources required for the successful implementation of the positioning control system. These include material, capital, intellectual, labor, immaterial, and informational resources. A detailed justification of capital investments, crucial for the project's implementation, is presented in Table 4.6.

Table 4.6 - Justification of Capital Investments for Project Implementation

(Amounts in CNY)

Articles of Capital Investment	**Amount (thousand CNY)**
Direct Material Costs	
- Raw materials and materials excluding returned waste	2,240
- Purchasing semi-finished products and components	880
- Fuel and energy consumption	400
- Spare parts costs	880
- Other material costs	400
Direct Labor Costs	
- Wages for production workers	9,600
- Bonuses, incentives, compensation for production workers	4,800
- Vacation pay for production workers	2,400
- Other idle time costs for production workers	800
Social Deductions to the Pension Fund (22% of wages)	5,555.20

Costs for Fixed and Intangible Assets	
- Initial cost of assets involved in production (including transportation, installation, and dismantling)	800
Other Direct Costs	
- Research and development for innovative products	3,200
- Services from third-party enterprises (security, advertising, rent, etc.)	1,600
- Utility bills	2,400
- Loan returns and maintenance	1,200
- Direct other costs	2,400
Total Expenditures	
- Production management costs	8,000
- Fixed assets and intangible assets for general production	6,400
- Technology improvement and production organization	2,000
- Costs for maintenance of production premises	640
- Labor protection, safety equipment, and environmental protection	1,200
- Other general production costs	1,200
Total Capital Investments for Project Implementation	59,095.20

This table details the capital investment required to implement a positioning control system to ensure the accuracy of financial planning. These categories cover all aspects of a project, from direct material and labor costs to broader expenses related to production management and technology upgrades. This comprehensive budget is critical to the strategic planning and financial management of the project.

4.5 Key Activities and Key Partners

This subsection elaborates on the methods employed to achieve the objectives set for the development of the positioning control system. The key tasks and activities are summarized in Table 4.7, providing a clear overview of each step in the process.

Name of Activity	Description of Activity	Activity Result
Problem Analysis	Investigating the challenges in precision control and adaptability	Identification of key issues and potential solutions
Process Study	Evaluating effective processes for enhanced control and precision	Modeling and simulation of the control system
Design Phase	Designing the control system and its components	Detailed drawings and design specifications
Production	Manufacturing parts and assembling the control system	Completed and functional control system unit
System Implementation	Setting up and integrating the system into the desired environment	Successful deployment and operational system

In addition to these activities, the success of the project is significantly influenced by collaborations with key partners. These partners provide essential resources and services critical for the project's execution. Table 4.8 lists the primary partners involved in this project.

Table 4.8 - Key Partners

Partner Name	**Location**	**Legal Status**	**Role**

Advanced Robotics Solutions Ltd.	Shanghai, China	Limited Liability Company (Ltd.)	Development of advanced robotic components for integration into the control system.
GreenTech Energy Innovations Inc.	Beijing, China	Corporation	Providing energy-efficient solutions and materials for the control system.
Precision Manufacturing Group	Shenzhen, China	Partnership	Fabrication of high-precision mechanical parts for the control system.
DataStream Analytics Co.	Hangzhou, China	Private Company	Supplying software and data analysis tools for system optimization.
UniTech University	Nanjing, China	Educational Institution	Research collaboration and testing, providing technical expertise and resources.

In this section, Tables 4.7 and 4.8 concisely capture the core activities and the key partners involved in the development and implementation of the positioning control system. This structured approach ensures clarity in understanding the project's workflow and the collaborative efforts required for its success.

4.6 Financial Justification of the Startup Project

The financial justification of the positioning control system project entails a comprehensive analysis of the cost price, which encompasses all production costs associated with manufacturing and delivering the system. Following the Provisions (Standard) of Accounting - 16 "Costs", the cost classification is divided into five main economic elements, detailed in Table 4.9. This table provides a structured overview of the various cost elements involved in the production of the positioning control system. It includes direct costs like materials and labor, as well as indirect expenses such as depreciation and other operational costs. This detailed breakdown is crucial for understanding the financial feasibility of the project and ensuring accurate pricing of the final product.

Table 4.9 - Production Costs by Economic Elements

Production Cost Element
Direct Material Costs
- Raw materials and materials (excluding returned waste)
- Purchasing semi-finished products and components
- Fuel and energy consumption
- Packaging and packaging materials
- Construction materials
- Spare parts
- Agricultural materials
- Other material costs
Direct Labor Costs
- Wages according to rates and tariffs
- Bonuses, incentives, compensation payments, vacation pay
- Payment for other unworked time
- Other labor costs
Social Deductions (22% on wages to the Pension Fund)
Depreciation of Assets
- Fixed assets and non-current intangible assets
- Other non-current tangible assets
Other Direct Costs
- Research and development costs
- Cost of works, services of third-party enterprises, and communal services
- Rent, loan repayments, and their maintenance
- Losses due to technological defects
- Costs of realized production stocks
- Bad debts, operational exchange rate differences, stock depreciation
- Fines, penalties, and other operating expenses
Total Expenditures

4.7 Target Groups of Potential Users

In the context of the positioning control system designed specifically for elevator drive control, it is essential to identify the primary user groups and stakeholders. This section outlines the key target groups and how the system meets their specific requirements in the domain of elevator technology.

1. Elevator Manufacturers:

- Needs: High precision and reliability in elevator control systems, safety, and energy efficiency.

- System Benefits: The positioning control system offers exceptional precision and reliability, crucial for the safe operation of elevators. Its energy-efficient design can lead to significant cost savings and contribute to sustainable building practices.

2. Commercial Building Developers and Owners:

- Needs: Dependable elevator systems that ensure passenger safety and efficient building operation.

- System Benefits: The system's reliability and efficiency make it ideal for commercial buildings, where elevator downtime can have significant implications on daily operations.

3. Residential Complexes and Housing Societies:

- Needs: Smooth and safe elevator operations, low maintenance costs.

- System Benefits: The system provides a smooth operational experience and is designed for longevity, reducing maintenance frequency and costs.

4. Hospitality Industry (Hotels, Resorts):

- Needs: Elevators that provide comfort, safety, and reliability for guests.

- System Benefits: The system ensures a comfortable and safe riding experience, essential in the hospitality sector where guest comfort is paramount.

5. Healthcare Facilities (Hospitals, Clinics):

- Needs: Elevators with utmost reliability and quick response times for emergencies.

- System Benefits: The system's reliability and quick response capabilities are crucial in healthcare settings, where elevator speed and efficiency can impact patient care.

6. Transportation Hubs (Airports, Metro Stations):

- Needs: High-capacity elevator systems capable of handling heavy footfall.

- System Benefits: The system is designed to efficiently manage high-traffic situations, ensuring reliable operation in busy transportation hubs.

7. Maintenance and Service Companies:

- Needs: Easy-to-service control systems with diagnostic capabilities.

- System Benefits: The system is designed with serviceability in mind, offering easy access for maintenance and advanced diagnostics for swift troubleshooting.

This section identifies the key market segments for the elevator drive control system. By focusing on the specific needs of each target group, from safety and reliability to energy efficiency and maintenance ease, the positioning control system is poised to meet the diverse demands of the elevator industry.

4.8 Target Groups of Potential Consumers

In identifying potential consumers for the elevator drive control system, it's crucial to determine the target groups that will be provided with the device or technology and to decide on an appropriate market coverage strategy. These strategies include concentrated marketing for developers focusing on a specific market segment, differentiated marketing for developers targeting multiple market segments with separate impactful plans, and mass marketing for developers offering a standardized project to all market participants.

Table4.10. Selection of Target Groups of Potential Consumers

Description	Target Needs Within the Segment	Competitive Intensity in the Segment	Ease of Entry into the Segment
Equipment Manufacturers	High precision and reliability	High	Moderate
Commercial Buildings	Safety and efficiency	Medium	Easy
Residential Areas	Low maintenance costs	Low	Difficult
Medical Facilities	Quick response capability	High	Moderate
Transportation Hubs	Ability to handle high passenger volume	Medium	Difficult

The selection of target groups depends on the specific consumer groups referred to by the equipment or technology.

Table 4.11. Definition of Basic Development Strategies

Selected Project Development Alternatives	Market Coverage Strategy	Key Competitive Position Based on the Selected Alternative	Basic Development Strategy
High-Quality Equipment	Differentiated Marketing	Leader	Differentiation Strategy
Energy-Saving Technology	Concentrated Marketing	Breakthrough	Concentrated Strategy
Wide Application	Mass Marketing	Follower	Mass Strategy

4.9 Sales Channels for Elevator Drive Systems

Sales channels are a critical component of bringing elevator drive systems to market. They encompass the various entities and methods involved in the physical distribution of these systems, ultimately facilitating the transfer of ownership from manufacturers to consumers. While manufacturers may relinquish some control over the sales process when utilizing intermediaries, the benefits of engaging with these entities are widely recognized. It is essential to define the sales approach, whether through direct sales efforts or by involving third-party intermediaries, and to identify the specific needs and types of intermediaries required for success.

Determining the optimal sales system for elevator drive systems involves describing the sales process comprehensively. This process includes conducting business negotiations, participating in trade seminars, and showcasing the capabilities of the elevator drive technology, along with its advanced operational methods.

Table4.12. Composition of the Sales System for Elevator Drive Systems

Specifics of Target Customer Buying Behavior	**Sales Functions Executed by Product Suppliers**	**Optimal Sales System for Elevator Drive Systems**
Elevator drive system purchases are primarily made through construction project contractors and elevator installation companies. These customers typically require consultation and technical support during the selection and installation of elevator drive systems.	Sales functions executed by the elevator drive system supplier include product consultation, technical support,and customization to meet specific project requirements.	The most efficient sales system for elevator drive systems involves establishing strong partnerships with construction project contractors and elevator installation companies. This includes offering comprehensive technical support, product customization, and tailored solutions to meet project-specific needs. Engaging in trade shows and industry events to showcase the technology's capabilities and benefits is also crucial for market penetration.

4.10 Project Initiation Risk Analysis for Elevator Drive System under Robust Control

The initiation of a project, especially one involving the implementation of an elevator drive system under robust control, necessitates a thorough risk analysis to ensure its success. This section focuses on identifying and addressing potential risks associated with this specific project.

Innovation Risk:

Implementing a cutting-edge elevator drive system introduces innovation risk. This risk stems from uncertainties surrounding the acceptance of the new technology in the market. Factors such as market demand, technological compatibility, and the ability to deliver as per expectations are pivotal in assessing this risk. The innovation risk in this context can manifest in several ways:

- Market Demand: Uncertainty regarding whether there will be sufficient demand for the new elevator drive system.

- Technological Compatibility: The possibility that the new technology may not align with the technical requirements of elevator systems.

- Market Acceptance: The risk that the newly acquired technology might not find quick adoption due to compatibility issues or shortcomings in meeting technical requirements.

To mitigate innovation risk, strategies such as acquiring ownership of established innovations, participating in qualified innovation projects with contractors, and establishing contingency plans for risk threats should be considered.

Project Risk:

The development phase of the elevator drive system project involves inherent risks, which must be managed effectively. The project risk factors include:

- Financial Risk: Ensuring financial stability throughout the project and securing appropriate financing.

- Organizational Risk: Streamlining organizational efficiency across departments during project implementation.

- Logistics Risk: Ensuring efficient resource supply and maintaining technical efficiency in dealings with suppliers and contractors.

- Human Resources Risk: Ensuring that project team members possess the necessary professional skills, exhibit initiative, and can collaborate effectively.

- Marketing Risk: Developing a clear and balanced marketing strategy for introducing and executing the project in the market.

Uncertainty and Risk Parameter Adjustment:

Uncertainty is a fundamental aspect of project initiation. It involves formulating potential project implementation conditions, transforming initial information about uncertain factors into actionable plans, and confirming the overall project performance indicators. Risk parameter adjustments may be necessary to align project values with expected outcomes.

Categorizing Risk:

Risk can be categorized into static and dynamic risks based on their nature:

- Static Risks: These represent real threats to assets, such as property issues, inability to withstand asset losses, and typically lead to losses.

- Dynamic Risks: These arise from unforeseen changes in asset values, incorrect management decisions, market fluctuations, and political changes. Dynamic risks are often hard to predict and control.

Industrial, Business, and Financial Risks:

For the elevator drive system project, it's essential to consider industrial, business, and financial risks:

- Industrial Risk: Risks related to production losses, equipment damage, and new technology introduction.

-Business Risk: Risks related to sales, transportation, buyer perception, and market conditions.

- Financial Risk: Risks associated with financial operations, including currency risk, credit risk, and investment risk.

Addressing these risks comprehensively during the project's design phase is crucial for its success.

In conclusion, the initiation of a project involving an elevator drive system under robust control requires a comprehensive risk analysis that covers innovation, project-related, uncertainty, risk categorization, and various types of risks. Effectively managing these risks is essential for the successful implementation of the project.

4.11 Project effectiveness and attracting investors

The success of an entrepreneurial project for an elevator drive system under robust control depends critically on its effectiveness and attractiveness to potential investors. In this section, we will explore modern technical methods for assessing the effectiveness of this startup and its attractiveness to investors.

Project Effectiveness Evaluation - Achieving Profitability in 3 Years

1. Initial Investment:

Initial hardware and software development costs: RMB500,000

Team salaries and operating expenses: RMB300,000

Total initial investment: RMB800,000

2. Annual Cash Flows:

Expected sales revenue in Year 1: RMB200,000

Expected sales revenue in Year 2: RMB600,000

Expected sales revenue in Year 3: RMB1,000,000

3. Return on Investment (ROI):

Investment Payback Period (Tpb): 2 years (assuming annual net profits are used for investment payback)

4. Net Present Value (NPV):

Discount rate: 10%

NPV Calculation: $NPV = \frac{CF_0 + \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i}}{(1+r)^n}$

where: CF_O: - represents the initial investment: RMB800,000; CF_I:represents the cash inflow in Year i (sales revenue - costs), r is the discount rate, which is 10%; n is the evaluation period, which is 3 years

5. Loan-to-Cost Ratio (LTC):

Loan amount: RMB500,000 (assuming a portion of the project funding comes from a loan)

Total project cost: RMB800,000

LTC Calculation: $LTC = \frac{500000}{800000} = 0.625$

6. Loan-to-Value Ratio (LTV):

Loan amount: RMB500,000

Property appraisal value: RMB1,000,000

LTV Calculation: $LTV = \frac{500000}{1000000} = 0.5$

7. Net Discounted Value (NPV):

Project cash flow data: Calculated based on annual sales revenue and costs,Discount rate: 10%

NPV Calculation: $NPV = \frac{CF_0 + \sum_{i=1}^{3} \frac{CF_i}{(1+0.10)^i}}{(1+0.10)^n}$

8. Investment Payback Period (Additional Investment):

Additional investment: RMB0

Average annual cash flow (CF): Calculated based on annual sales revenue and costs

Investment payback period calculation: $Tpb = \frac{800000}{(200000 + 600000 + 1000000)} = 0.8 years$

Evaluation Results:

Based on the above data and indicators, the project achieves a return on investment (ROI) in the second year and starts generating profits in the third year.

The Net Present Value (NPV) is positive, indicating that the project's present value exceeds the initial investment and has the potential to attract potential investors.

The Loan-to-Cost Ratio (LTC) is 0.625, which is less than 1, indicating partial financing support for the project.

The Loan-to-Value Ratio (LTV) is 0.5, indicating that the project's debt relative to the property value is low.

The Investment Payback Period (Additional Investment) is 0.8 years, indicating a relatively fast capital recovery.

Taking these indicators into consideration, the robustly controlled elevator drive system startup project shows a high level of effectiveness in achieving profitability within 3 years and has the potential to attract investors. However, investment decisions should also consider factors such as market competition, industry trends, and risk management to ensure the project's long-term success.

Business model of the project

The business model of the OptiVent Solutions project is a key aspect of its commercialization and defines an effective way to achieve the set goals. Building a competitive business model is a strategic step that takes into account the most important aspects of the project. In table 4.13. the structure of the business model is presented.

Table 4.13. – Equipment Business Model Structure Table (Technology

<table>
<tr><td rowspan="2">Key partners
Technological partners
- General Electric
-Arcelor Mittal
- Bosch
- Samsung</td><td>Key activities
-development
-production
-support</td><td rowspan="2">The value of the offer
Innovative control unit for lifting systems</td><td>Customer relations
- direct sales
-support</td><td rowspan="2">Consumer segments
- architects
- premises managers
- manufacturers of equipment</td></tr>
<tr><td>Key resources
- technical crew
- developers
- sales</td><td>Sales channels
- direct sales
- distribution</td></tr>
<tr><td colspan="3">Cost structure
- capital
- permanent
-variable costs 200 thousand UAH.</td><td colspan="2">Income streams
- equipment sales
- technical support services</td></tr>
</table>

This business model involves close partnerships with key technology players, active involvement of architects and facility managers through direct sales and strategic partnerships. Technical support and innovative solutions to optimize energy consumption and air quality make the offer profitable for a wide range of consumers, ensuring a stable income stream.

CONCLUSIONS ABOUT CHAPTER

Chapter four delves deep into the crucial aspects of project initiation and risk analysis, both of which are paramount for the success of a project. During the project initiation phase, it is imperative to clearly define the project's objectives, scope, and key elements, as well as identify the project team and allocate resources effectively. Simultaneously, the project team must identify and address potential risks to mitigate their potential impact on the project.

The first step in project initiation is to clearly define the project's goals and vision. These objectives should be specific, measurable, and aligned with the organization's strategic goals. Additionally, the project's scope needs to be well-defined to ensure that the work and deliverables are clearly visible. At this stage, it is also essential to identify key team members and leaders and allocate the necessary resources to support the smooth implementation of the project.

Project initiation also requires a focus on risk analysis, which is a critical factor in ensuring project success. During the project initiation phase, it is necessary to identify potential project risks, including technical, market, financial, and management risks. The identified risks need to be assessed, determining their probability and impact to prioritize which risks require immediate attention. Additionally, risk mitigation strategies, including avoidance, transfer, mitigation, and acceptance strategies, should be formulated to reduce the potential impact of identified risks.

Finally, the project initiation phase necessitates an assessment of the project's appeal, including financial metrics such as Net Present Value (NPV), payback period, loan-to-cost ratio, and more. These metrics help determine whether the project can attract investor interest. By considering the project's objectives, scope, team, resource allocation, risk analysis, and attractiveness assessment, a solid foundation for the project's success can be established.

Table 4.14. - Summarizing technical and economic indicators

Indicators	Indicators
Annual output, units	200
Capital investment, thousand UAH.	200
Cost of production, thousand UAH.	100
Product price, thousand UAH	150
Profit, thousand UAH.	50
Profitability, %	33%
Coefficient of economic efficiency	1.5
Return period of capital investments, years	4

The general conclusion is that this solution is a promising and effective innovative solution for the market, capable of ensuring sustainable financial success and meeting the needs of customers.

CONCLUSIONS

1. The paper analyzed the existing electromechanical systems of elevator installations present on the market of Ukraine and determined that the most popular is the scheme with an asynchronous motor and a worm gear, in which the speed changes from a frequency inverter.
2. For the analysis and synthesis of the robust control system, the elements of the automation system and the corresponding parameters of the positional electric drive model were selected in the work, which allow to carry out research using the digital modeling method.
3. To ensure a high level of robustness to external and parametric disturbances of the system, a robust regulator was synthesized, which ensures the input of an additional correction signal by branching relative to the reference transient process.
4. Research using the digital modeling method made it possible to verify the functionality of the proposed algorithm, and its subsequent implementation in Codesys v.2.3. confirmed its functionality in practice.

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